Remote Sensing of Environmental Change in the Niger Delta, Nigeria

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By

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ABSTRACT

This study examines landuse change (LUC) in the Niger Delta of Nigeria, focusing on the drivers of change and the societal implications on the people in the Delta. This study applies both remote sensing and social research methods to evaluate the spatial and temporal change in landuse, population change, deforestation, and degradation within forest reserves; and the impacts of oil production and the effects of the changes on the Delta. A time series of Landsat TM images was used over the period from 1984 to 2011. The study evaluates a number of classification and post-classification change detection methods to examine LUC, while NDVI is used to monitor the degradation of forests. Accuracy assessment shows that Maximum Likelihood (ML) is the most accurate method, but results were still error prone. To improve classification accuracy, a Decision Tree Reclassification (DTR) method was developed that uses prior classifications and simple rules of those LUCs, which occur over time and those that do not. DTR improves the overall accuracy of the classification from 62% to 89%. The social methods used a mixed-method approach (questionnaires, interviews and focus group discussions). The methods were carefully selected and used to help explain the results of findings from remote sensing. The results are presented in two phases: (1) results of remote sensing showing the overall changes in the entire Niger Delta and specific case studies (2) results of social science survey showing the drivers of changes and their environmental and societal implications on the people in the Delta. The results show that nearly 9000 km^2 forest has been lost in the Niger Delta region between 1984 and 2011, but the extent of deforestation varies from one forest type to another. Lowland rainforest is more exploited than freshwater swamp forest and mangrove forests, with approximately 40% of lowland rainforest areas lost. The urban areas expand by about 50% in lowland rainforest, but less urban expansion is noted in freshwater swamp forest (16%) and mangrove forest (38%). The study finds that assessing oil spill impacts using Landsat TM was not possible, but that oil production infrastructures (e.g. construction of canals) can be an important cause of deforestation in the Delta in exceptional cases. This is evident in the mangroves around Tsekelewu that are reduced from 200km^2 in 1984 to 114km^2 in 1987, because of the construction of artificial canals that have promoted regular inflow of seawater and the consequent destruction of freshwater mangroves. The results from social survey show also the drivers of LUC and deforestation in the Delta are probably multiphase including unenforced forest protection laws; corruption at all levels; pressure of immigration and increasing population; and indifference of local people to the state of the forest around them.

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CHAPTER ONE
INTRODUCTION

1.1. General Background of the Study

Assessing the drivers and the impacts of global environmental change has been the major concern for scientists over several decades. Increasing demand for environmental recourses by a rapidly growing population, coupled with fast urbanization and industrialization, has resulted in environmental changes all over the world. Consequently, scholars and many international organisations have been investigating the impacts of natural and anthropogenic activities on environmental resources. The scientific studies of the drivers and impacts of environmental change is not confined only to the international level, because man-environmental relationship can be said to have the same origin as man first appearance on earth. Two major terms were frequently employed in previous environmental change studies- "landuse and landcover change". It is essential here however, to distinguish and define these terms from the onset of this thesis.

Landcover is distinct from landuse, though the two terms are often being used interchangeably. According to Ellis (2007), landcover refers to the physical and biological materials on the surface of the earth. These include water, vegetation, soil, and may even include artificial structures. Landuse on the other hand is a description of how people utilize land resources (FAO 1995; Lambin *et al*. 2003). Thus, the term Landuse includes the social and economic purposes and contexts for and within which lands are managed (or left unmanaged), such as subsistence versus commercial agriculture, rented vs. owned, or private vs. public land (Lambin and Ehrlich 1997). Land has been used by people to meet their needs, since the first life on earth. Land has been used to move around, to rest, to settle, and to feed people. These human activities alter land surface processes such as biogeochemistry, hydrology, edaphic and biodiversity to create artificial environment (Lambin and Ehrlich 1997; Seto *et al*. 2002). Many regions around the world undergo rapid environmental changes because of human activities and natural phenomena but landcover today is altered principally by direct human use (Serneels and Lambin, 2001). Changes in the nature of landuse activities often results in landcover changes (Foody 2003).

Therefore, the majority of previous studies have employed the term “landuse” change because the spatial and temporal rates at which man utilizes land - for cultural, social and economic purposes - usually determines the pattern of environmental change of a region (Lambin and Ehrlich 1997; Wunder 2000; Geist and Lambin 2001; Ellis 2007). Consequently in the present study, the term landuse is used throughout, because landuse change is one of the most important variables of environmental change and represents the largest threat to ecological systems in the Niger Delta. Studies have shown that in the last three hundred (300) years, the impacts of land use change have increasingly assumed from significant to threatening proportions. In the present study, the term landuse is associated with changes in the uses of land which cause major concerns in the Niger Delta of Nigeria. For example, earlier studies have noted that conversion of cropland and forest land into urban uses, is one of the important type of landuse change in the tropical country because of its serious socio-economic and environmental implications (Lambin *et al.* 2001; Geist and Lambin 2002; Foody 2003; Gasparr *et al.* 2010). Assessing landuse change is important because it is human activities (resulting from landuse), not nature’s agents, that bring about these environmental changes, and which is responsible for their magnitude and severity of landuse (Gautam 1983; Foody 2003). Understanding of landuse change provides lessons for a transition to environmental sustainability (Lambin *et al.* 2001; Shi *et al.* 2002). Recent studies (Meyfroidt and Lambin 2008; Wang *et al.* 2009; Akumu *et al.* 2010; Bateman *et al.* 2011) have found that this understanding assists in monitoring and modelling the dynamics of environmental change resulting from increasing population, and resulting in agricultural, industrial and urban demand for land.

To achieve this level of understanding, several methods have been developed and used to assess and map landuse change in order to provide adequate information on the use of land resources, for better planning and management (Lambin and Ehrlich 1997; Kreuter *et al.* 2011). These methodologies can be grouped into two: ground based methods (such as field observation and use of questionnaires) and remote sensing techniques (Eastman and Fulk 1993; Ojirna *et al*. 1994; Pandy and Nathawat 2006). Nonetheless, it is clear from literature that it is difficult to effectively monitor spatiotemporal changes in landuse with conventional ground methods (Dixon *et al.* 1994; Wang *et al.* 2010) and they are not cost effective (Dimyati *et al.* 1996; Meyer 1995; Yang and Liu 2005).

For that reason, the application of technologies such as remote sensing and geographic information systems (GIS) provide an alternative means of measuring the extent and pattern of changes over a period of time (Han, *et al.*2004; Boakye *et al.* 2008). Chen (2002) and Ouyang *et al.* (2010) have noted that the fast developing technology of remote sensing offers an efficient and speedy approach for mapping of basic land-use types over large areas. Indeed over the past few decades, remote sensing techniques have been employed by many researchers to investigate change in landuse (Rao *et al.* 1999; DeFries and Belward 2000; Gonzalez 2001; Shi *et al.* 2002; Ruiz-Luna and Berlanga-Robles 2003; Gao and Liu 2010). It has been shown in these studies that remote sensing is not only good for preparing landuse change maps and observing changes at regular intervals of time, but also cost and time effective. For example, Landsat data have been used to analyse environmental change in different scales since the launch of Landsat MSS in 1972 (NRSA 1978; Salami 1999; Akumu *et al.* 2010). However, it is apparent from literature that remote sensing of environmental change is influenced by a complex set of factors and different studies sometimes arrive at different conclusions about which landuse change detection techniques are most effective (Geist and Lambin 2001; Lu *et al.* 2004).

1.2. The Research Problem

Landuse change has become a matter of public, political and academic concern in the Niger Delta of Nigeria over the past few decades. The Niger Delta is a low-lying region within the continental shelf of the Atlantic Ocean (Figure 1.1), a major oil producing region in Nigeria and oil production in this region is the largest in the African continent (Ebeku 2006; Atakpo and Ayolabi 2009). Thus, the region is crucial to the economic development of Nigeria; as the main revenue generator for the country is through extensive oil and gas production. Over the years, the massive increase in oil revenue has not only created rapid wealth for the country, but also resulted in an increase in population in the Delta (Ashton-Jones 1998). Hence, demand for land resources by a fast-growing population, together with pressures from rapid urbanization, agricultural land expansion and oil production infrastructure have had a large impact on environmental resources in the region (Mmom and Arokoyu 2010; Fasona *et al.* 2011). Unfortunately, these resources are exploited without efficient management.

Figure 1.1. Location of Niger Delta within Gulf Guinea in the Southern part of Nigeria (Modified from blessed hope academy)

In spite of the impacts of oil exploration activities and production infrastructures in the region, vast deforestation resulting from commercial logging, firewood collection by local people, clearing of the forest for agricultural purposes, and urban encroachment on farmland/forest constitute serious environmental problems in the Niger Delta (Mmom and Arokoyu 2010). To ensure effective management and utilization of environmental resources for sustainable economic development in the Delta, there is a need for an in-depth and integrated study of spatiotemporal landuse change.

In general, the majority of previous studies have revealed that extraction of oil has been a major factor of deforestation, biodiversity loss; destruction of land resources and landuse conflict in the Niger Delta (Kalu and Izekor 2006; Kamalu and Wokocha 2010; Mmom and Arokoyu 2010; Onojeghuo and Blackburn 2011; Ugoh and Ukpere 2012). For example, studies by Kalu and Izekor (2006) and Kamalu and Wokocha (2010) have noted that oil generated environmental impacts in the region has made it extremely difficult for farming and fishing, leading to destruction of vegetation. However, other recent studies have found that the issues of land conflict in the Delta are a result of change in landuse in the region (Ugoh and Ukpere 2012). These imply that landuse issues in the Niger Delta is a complex problem, factors of which is beyond impact from oil production alone, but more as a result of unsustainable use of land resources.

Surprisingly, compared to other parts of the world, little research has been conducted in terms of assessing the spatial and temporal landuse changes, their rates of occurrence and types in the Niger Delta region. Foremost among few recent studies on the Niger Delta is a study by Onojeghuo and Blackburn (2011), who examined spatial rate of forest transition in the region. Major reason for limited study in the region might be due to insecurity as a result of regular violence and lawlessness by indigenous ethnic groups (Frynas 2000; Aaron 2006). Conflicts and kidnapping are so frequent and this insecurity has affected quality and quantity of research into environmental problems. Therefore, applying remote sensing and GIS methods to examine environmental change in the region is not only cost and time effective, but also it provides a means of investigating environmental problems at regular intervals of time, in a region of recurrent unrest, where it is dangerous to conduct manual landuse changes.

1.3. Research Questions

From review of the environment and the drivers of environmental change in the Niger Delta, and the research conceptual model adopted for this study, some research questions arise:

i. Is it possible to use remote sensing data to examine rates and patterns of landuse change in the Niger Delta?
ii. What landuse change has occurred in the Niger Delta during the past thirty years?
iii. How can remote sensing and social science methods broaden our understanding of the factors of landuse change in the Delta, both the ones identified already, and those yet to be identified?
iv. What drives landuse changes and their environmental and societal implications on the Niger Delta?

1.4. Aim of the Research

The aim of this research is to examine environmental change in the Niger Delta using remote sensing and non-remote sensing approach. The study is focused on assessing the drivers of landuse change and subsequently evaluates their environmental and societal impacts.

1.5. Objectives of the Research

To achieve above general aim of the research, the following objectives were developed:

- Investigate the potential of Landsat TM images to assess landuse change during the last 28 years in the Niger Delta. This objective addresses the main research investigation which tends to know the possibility of using Landsat data to assess landuse change in the Niger Delta.
- To evaluate the merits and limitations of the remote sensing and non-remote sensing methods that might be employed to understand landuse change in the Delta. This objective involves critical review of different approaches (both social survey and remote sensing) used by previous studies to assess environmental change.
- To identify and assess where change is occurring, rates and types of change. Here, this objective addresses the question of what, where and the rate of landuse change that has occurred in the Delta during the past years.
- To evaluate the use of social data and social field survey techniques in furthering our understanding of the drivers of landuse in the Delta. This evaluation includes those drivers that have been identified in Niger Delta and those that were found in other parts of the world but not yet identified in the Niger Delta.
- To identify the major factors that determine landuse change and degradation. This focuses on examining the relationship between the changes detected by the remote sensing analysis and the environmental, societal drivers and their impacts on the people of Niger Delta.

1.6. Justification of the Study

During the past few decades, environmental degradation resulting in change in landuse; forest degradation; environmental pollution from oil and gas production and biodiversity loss have been the foremost environmental problems confronting the Niger Delta of Nigeria. These environmental problems have led to losses of biodiversity, arable land, lives and properties. Landuse change in the Delta is a critical issue, though political and economic issues take center stage in national subject matter nowadays, and environmental degradation in the region is yet to be seen as a problem. On the other hand, the people of the Niger Delta are highly dependent on this degraded environment for their source of livelihood. Local inhabitants traditionally make their living as farmers, fishermen and hunters through exploitation of the resources from land, water and forest. However, the environment, health, social and economic activities of the people were distorted as a result of the environmental degradation resulting from environmental exploitation activities of multinational oil companies and other industries in the region. Reports in the Niger Delta Regional Development Master-plan [NDRDMP] of 2006, UNDEP-EA of 2011 and other earlier studies stated that water borne diseases are the most critical health problems in the Niger Delta and the health and social-economic problems most closely linked with environmental degradation and pollutions from oil production in the region.

Despite these environmental challenges, little research has been conducted in term of assessing the rate of occurrence, types and drivers of environmental change, and examining social and health implications of change in the Niger Delta. One of the reasons for this may be due to lack of accurate data and insecurity, which are militating against qualitative research work and appropriate decision making, in respect of environmental problems in the region. There are no sufficient records or data on environmental issues such as rate of deforestation in some major forest reserves. Also, there are no accurate data on rate and severity of deforestation, rate of oil spillage (in terms of the quantity of spill per specific location), list of biodiversities, their loss, and conservation. Nigeria is known for the highest rate of gas flaring in the whole world, but amazingly, there are no available data on the rate and quantity (in cubic metres) of gas flared per day. This is because many of the multinational oil companies do not make information available about their operations (Watts 2008). Therefore, we have no idea of scale of environmental change in the region. On the other hand, security issue is another long standing concern in the Niger Delta, which has hindered quality research in the region. The region is known as a region rife with violent, conflicts, kidnappings and frequent killings. Despite these obstacles, there is no doubt that in-depth understanding and qualitative research on environmental change in the region is increasingly needed for better management and future planning.

Therefore, this research attempts to use remote sensing and social survey to quantitatively examine spatiotemporal change in the landuse of the Niger Delta. Remote sensing method is employed in this study because it is a fast method of acquiring up-to-date information over unsecure geographical area like the Niger Delta. Also, remote sensing offers a variety of advantages in data collection compared to other forms of data acquisition. Data from satellite imagery are not biased, unlike other means of data collection in which human irregularities and uncertainties are predominant. Using remote sensing techniques in this research, it is possible to measure occurrence and rate of environmental change in the Niger Delta without being affected by insecurity anxiety in the region. Moreover, the outcome of this research offers an incomparable opportunity for developing a multi-disciplinary approach to the appraisal, management and control of environmental change in the region. This is highly indispensable, if the Niger Delta is to recover from decades of environmental decline that has been inflicting the region by a variety of oil and gas explorations and other human activities.

1.7. Thesis Overview

The second chapter systematically reviews the key environmental issues in the Niger Delta focussing on population growth, agricultural expansion, deforestation, oil exploration impacts; biodiversity conservation measures, environmental legislation and security issue in the region. The last two sections of this chapter elucidate the possible drivers of environmental change and their societal implications in the Delta.

The third chapter reviews the existing literature relating to the various methods used to examine and monitor landuse change. Over four hundred and sixty (460) literature items including journal articles, books and other publications on environmental degradation, landuse change and conservation using remote sensing and related topics, have been consulted and summarised.

The fourth chapter explains the methods and procedures through which the research has been carried out. The dataset used consists of a time series of Landsat TM from 1984 to 2011 and social survey data. Remote sensing and social science methods were used to detect and examine spatiotemporal change in landuse and their societal implications in the Delta.

Fifth chapter presents the results and their deductions. Maps, tables and graphs are used to display spatial and temporal changes in the Delta environment, using specific case studies which include: Urban expansion in three cities; deforestations in three forest reserves and the impact of oil production activities on people of the Delta.

Chapter six is a discussion section. Here, the results of both remote sensing and social survey are fully discussed. The relationship between the changes detected by the remote sensing and social investigation are evaluated in order to link environmental, economic and societal drivers and their impacts on the people of Niger Delta.

The final chapter (Chapter Seven) summarises the findings, recommendations and conclusions. The main findings reveal the rapid dynamics of landuse change in the Niger Delta of Nigeria driven by both population growth and unrestrained development. The thesis ends by assessing the implications of this study, not only on the Niger Delta, but also on the whole Nigeria and Africa region. And, recommending further work, stating why studies like these are necessary and outlining the different sectors of Nigeria economy that will find the results of this study helpful for their own future use.

CHAPTER TWO
THE NIGER DELTA: ENVIRONMENT AND ENVIRONMENTAL PROBLEMS

2.1. Location and Size

The Niger Delta is situated in the Gulf of Guinean, the Southern part of Nigeria (Figure 2.1). There is no consensus among previous studies, about the extent of the Niger Delta. The majority of these studies defined the region in terms of political, economic and conflict issues in the region (Ebeku 2006). For example, reports of the Niger Delta Development Commission (NDDC) before 2000 defined the region in terms of oil producing states. However, this PhD study defines the region based on geographical definition accepted by most Nigerians, in terms of the Delta States.

The Niger Delta is a low lying area, being on average approximately 3.5m above sea level, has an area of about 112,110 square kilometres and makes up 12% of Nigeria's total land mass according to the NDDC (2006). The Delta cuts across nine states: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and River States (Figure. 2.1). It has a convex shoreline stretching for about 350km from the coastal boundary of Ondo State to the boundary of Cross River State (Figure 2.1). It is the largest wetland in Africa and the world’s third largest.

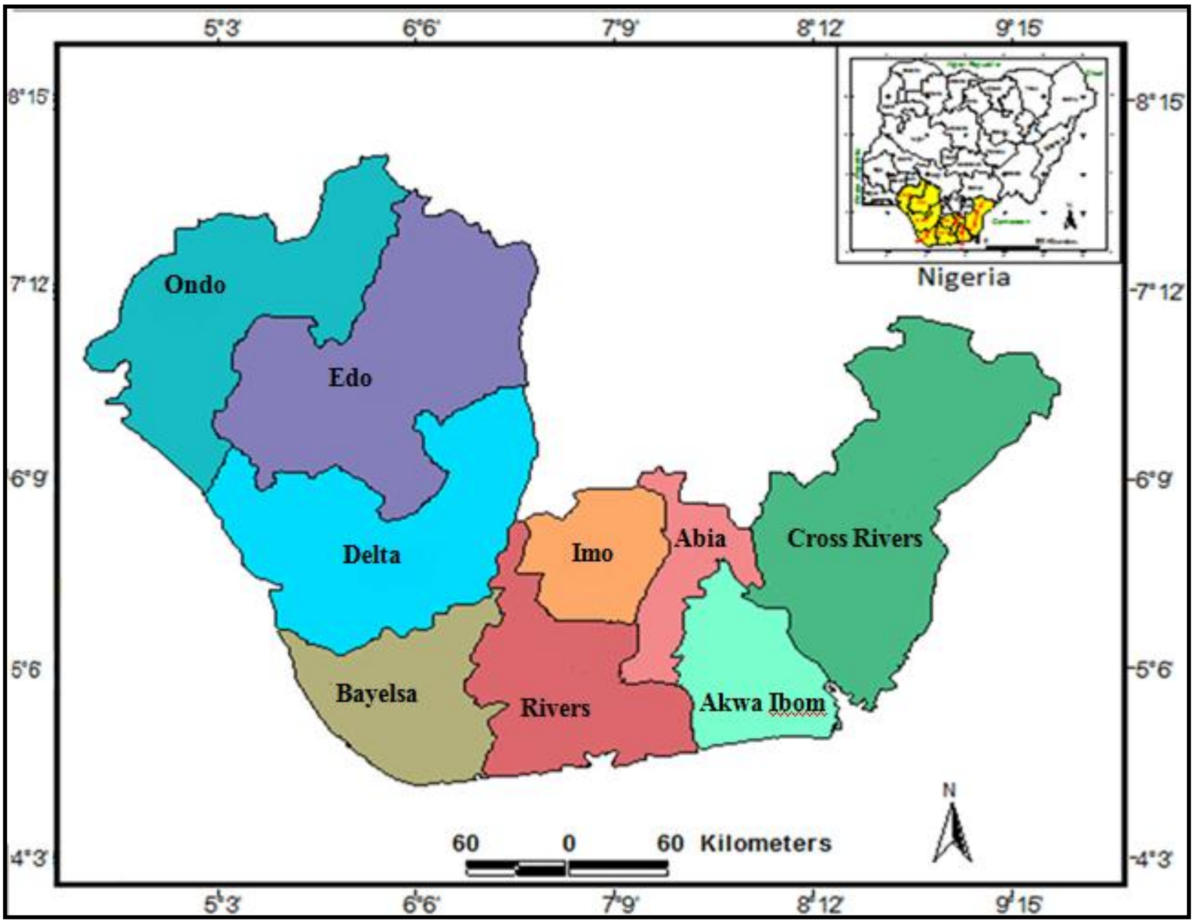

Figure 2.1. Map of the Niger Delta illustrating the location of nine states within the region.

The Delta is a large area of floodplain which is built up as a result of deposition and accumulation of sediments washed down for over about 100 million years from the Benue and Niger Rivers. The Niger River has its headwaters in Guinea, passing through Mali, the Republic of Benin, Niger and Nigeria (Figure 2.2). The Benue River has its headwaters in the Cameroon highlands and traverses both the Cameroon and Adamawa highlands (Figure 2.2). The Niger Delta consists of a diverse network of rivers and creeks (Figure 2.3), many of which are distributary channels of Niger River (Moffat and Linden 1995; CEDA 1997; Okonny 1988; Atakpo and Ayolabi 2009).

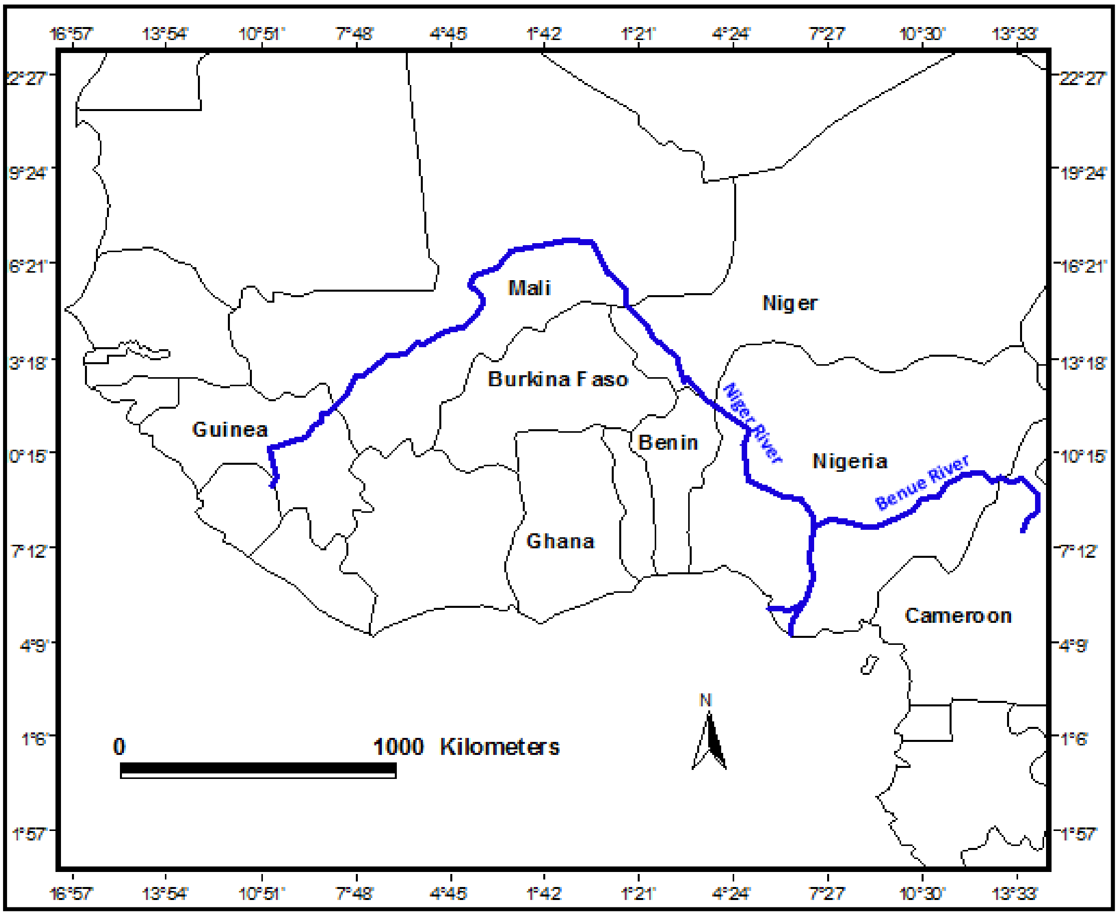

Figure 2.2. Map of West Africa showing the Niger and Benue Rivers.

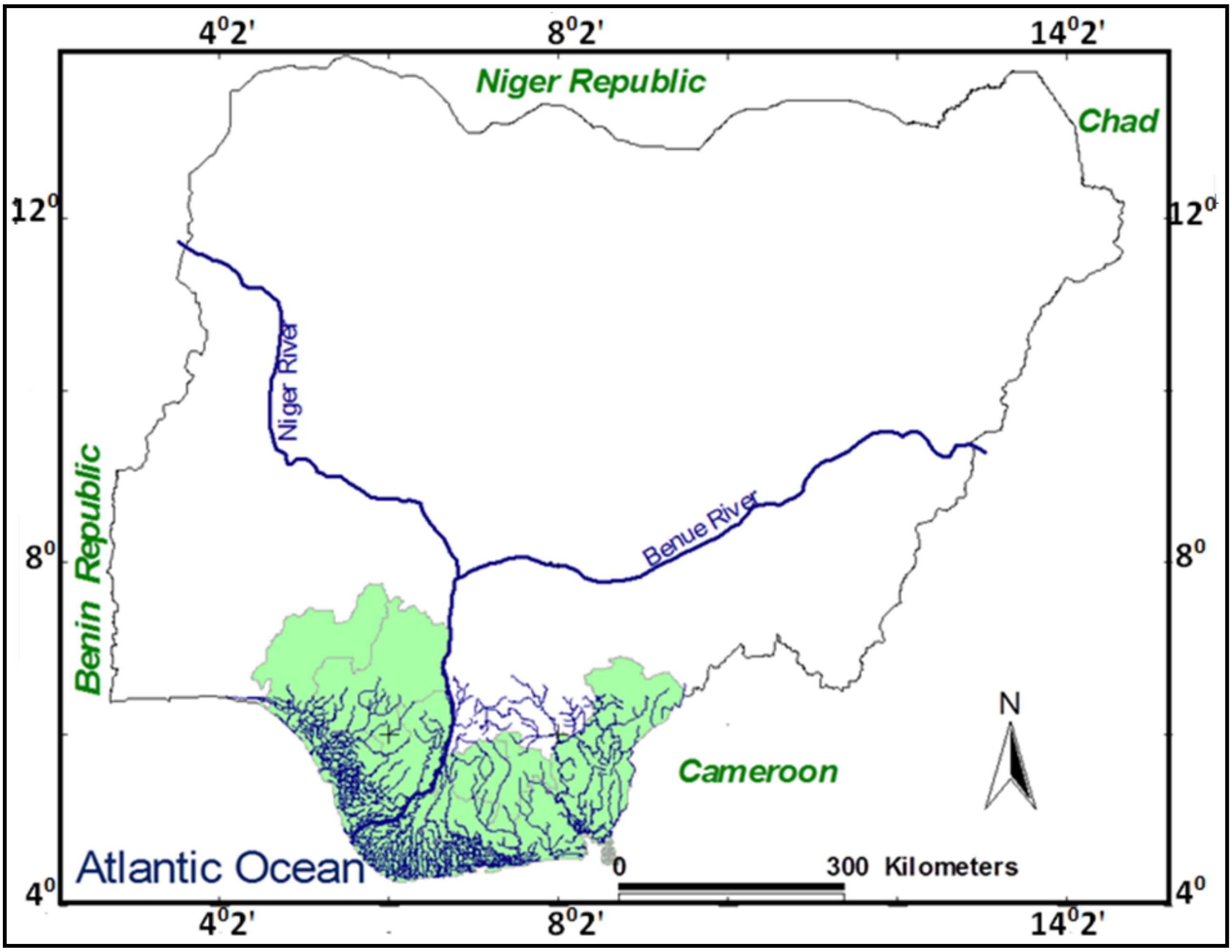

Figure 2.3. Map of Nigeria showing Niger and Benue Rivers. The shaded part of the map is the location of the Niger Delta with several tributary and distributary channels of the Niger River shown. The names of the neighbouring countries are in green.

2.2. Geomorphology of the Niger Delta

Our knowledge about the geomorphology of the Niger Delta is developed mainly from the previous works by Asseez (1975), Weber and Daukoru (1975), Okonny (1988), Doust and Omatsola (1990), Tuttle *et al*. (1999), Abam (2001) and other studies by researchers from the oil and gas multinational companies operating in the Delta. Understating the geomorphology of the Niger Delta aids a better understanding of the ecology, landuse and the drivers of environmental change in the region. Over long time scales, two main geomorphologic processes are predominant in the Niger Delta; these are marine transgression and regression (Asseez 1975; Okonny 1988). Generally, they are processes revealing the interaction between available space for potential sediment to accumulate. Transgression of the Delta occurs whenever the sediment accumulation exceeds the available space, whereas regression occurs when the available space for sediment accumulation exceeds the sediment supplied.

2.2.1. Geomorphologic Units of the Niger Delta

The Delta can be classified into seven geomorphologic units: The Lower Niger floodplain, Coastal sand plain, Mangrove zone, Deltaic plain, Western coastal plain, Beach Island and Band barrier island (Figure 2.4). The Lower Niger floodplain, according to Weber and Daukoru (1975), consists of sedimentary deposition of medium-coarse grained, point-bar sands and clayey back swamp deposits, while coastal sand plains include tidal flats and swamps behind barrier bars. The sediments in the Coastal sand plains vary from medium-coarse grained sands, fine clayey sands in natural levees to clayey and peaty deposits in swamps and lagoons (Tuttle *et al.* 1999). Deltaic Plain and Western coastal plain are non-tidal zones which are characterized by seasonally flooded small lakes. The Mangrove zone occupies inter-tidal land behind the Band barrier Islands, and consists of large estuaries with tidal effects, and reaches amplitude of approximately 1-3m (World Bank 1995). The Beach and Band barrier Islands occur along the coastal belt and consist of fine-medium grained sand. Swamps and beach ridges are common in this zone (Okonny 1988), caused by fluviomarine sedimentation (Tuttle *et al.* 1999).

2.2.2. Soils of the Niger Delta

The soils of the Niger Delta are closely related to the geological formations on which they sit, and the Delta geomorphology, being products of fluviatile processes, except for the Coastal Barrier Islands (Ibe and Njemanze, 1999; Atakpo and Ayolabi 2009; Were 2009). Nzewunwa (1980) classified the soils in the Delta into four major groups, Alluvial Soils on Marine Deposits, Hydromorphic Soils, Ferrallitic Soils; and Ferruginous Tropical Soils (Figure 2.5).

Alluvial Soils on Marine deposits are derived from marine sediments and recently deposited fluvial materials. Each year, annual floods add fresh materials into these soils. The top of these soils is characterised by brownish yellow fine sand and are highly suitable for the growth of both cash and food crops such as oil palm, rubber, coconut, yam, cassava, maize, and rice (Atakpo and Ayolabi 2009). Silt and clay make up about 41- 97%, while the rest is fine sand (Alaoga *et al.* 1988). Hydromorphic Soils are distinctive soils in the Niger Delta, whose composition is controlled by inter-annual water-logging and are derived from the underlying impervious shales. These soils are formed in the marshes and swamps of the Delta, which are usually flooded, especially during the wet season, thus the soils have a high water table. The nature of this soil type impacts negatively on agriculture, since the soils derived from shale are difficult to cultivate because of being waterlogging due to impaired drainage. A report of NDRDMP (2006) has also revealed that over 65% of soil in mangrove and freshwater swamp forests are found on Alluvial and Hydromorphic Soils.

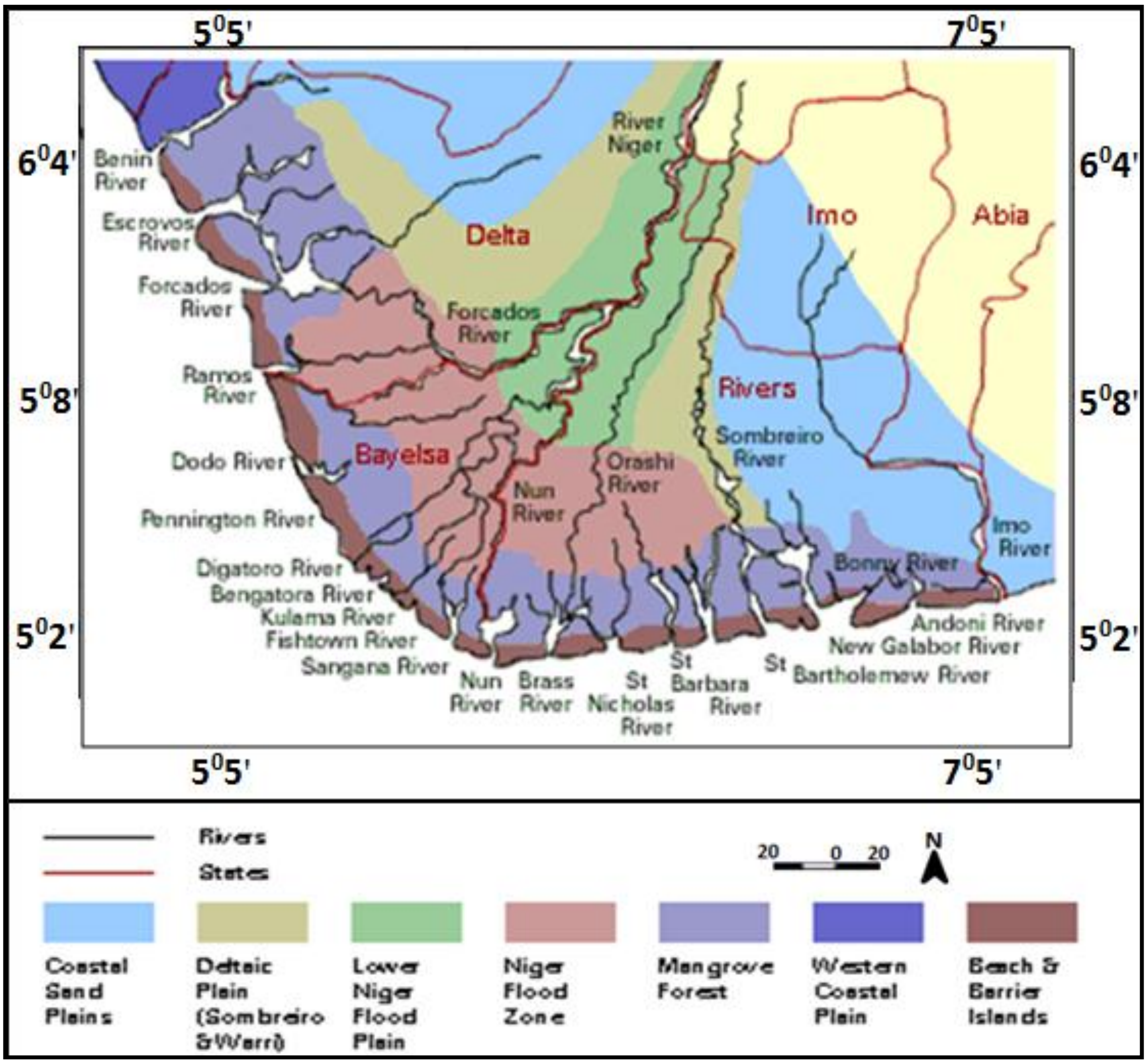

Figure 2.4. Map of the Niger Delta showing the geomorphological units (Source: Urhobo Historical Society, 2009).

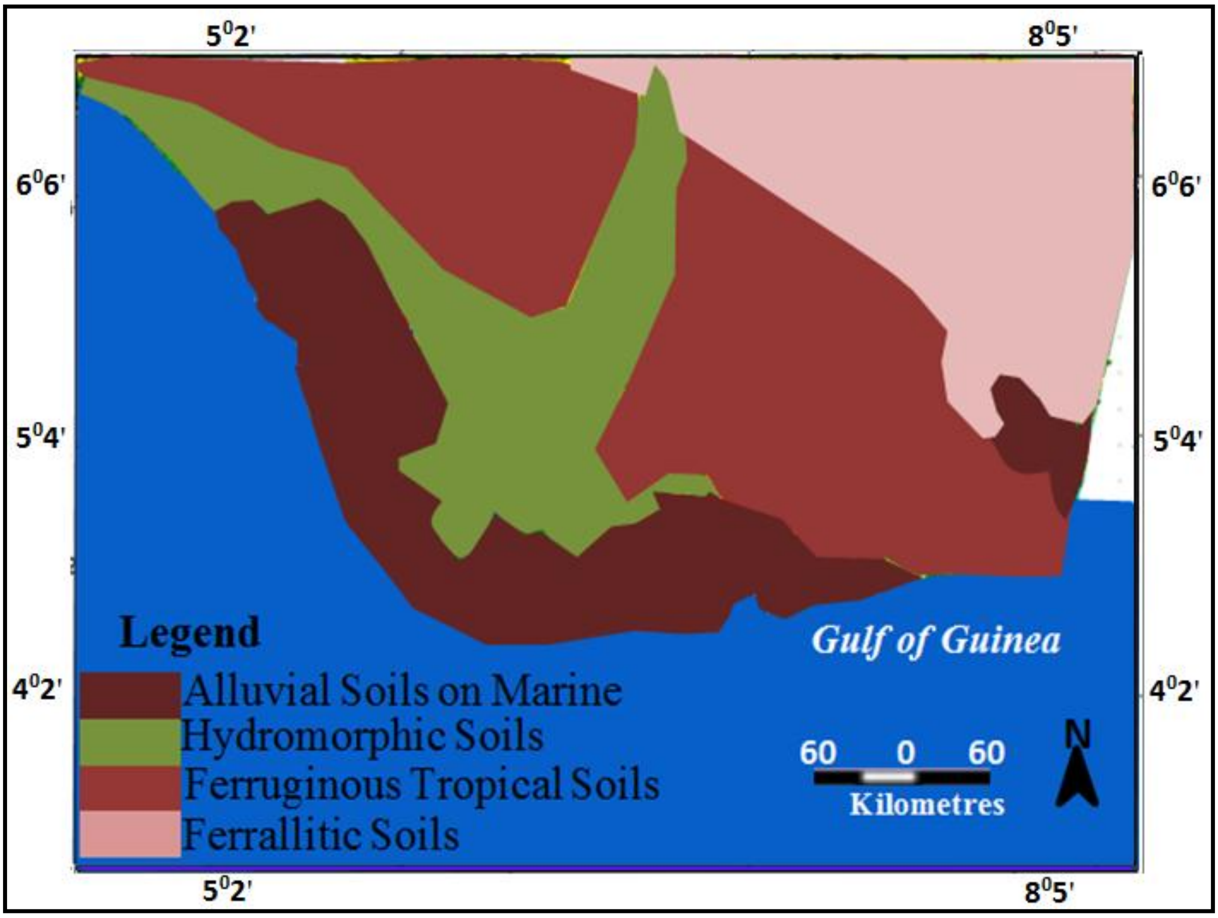

Figure 2.5. Map of the Niger Delta showing the major classes of soils.

Ferrallitic Soils, according to Nzewunwa (1980) are yellowish red gravelly and brown sandy soils which cover about 50% of the eastern part of the Niger Delta. These soils are rich in iron but possess low fertility. Many scholars referred to these deep porous soils as "acid sands". This is because the soils are derived from sandy deposits of the Niger Delta. Ferruginous Tropical Soils are red clayey soils which are derived from the basalts around Cross Rivers State. The basalts are the results of ancient volcanic activities occurring around Cross Rivers. These soils are rich in iron with an appreciable fertility (Atakpo and Ayolabi 2009; Were 2009). About 70% of Ferruginous Tropical Soils are found in the rainforest ecological zone of the Niger Delta. This soil zone has the highest fertility top-soils which are suitable for agriculture and tree crops (NDRDMP, 2006).

2.3. Climate of the Niger Delta

The Niger Delta experiences a tropical climate with an alternating wet and dry season. The average annual rainfall of the Niger Delta ranges from 2000 to 4021mm (Adejuwon 2012), with precipitation increasing from North of the Delta towards the coast (Figure 2.6). The peak of the wet season is from June to September with a little dry season in the month of August each year. December through January are months of the main dry season. Temperature is relatively constant throughout the year over the entire region with the average annual temperature of about 27^{o} C (Figure 2.7), with little seasonal variation (National Bureau of Statistics [NBS] 2006). High temperatures are recorded during February and March of each year, with slightly lower temperatures from June to September. This region is known for high surface humidity that rarely dips below 75% (Sorgwe 1997), with the coastal areas experiencing higher humidity than that of inland areas (Figure 2.8). The highest values of humidity (of about 80 to 90%) are usually recorded within the months of June through September, and lower humidity occurs from December to March. This is as a result of the proximity of the region to the Atlantic Ocean.

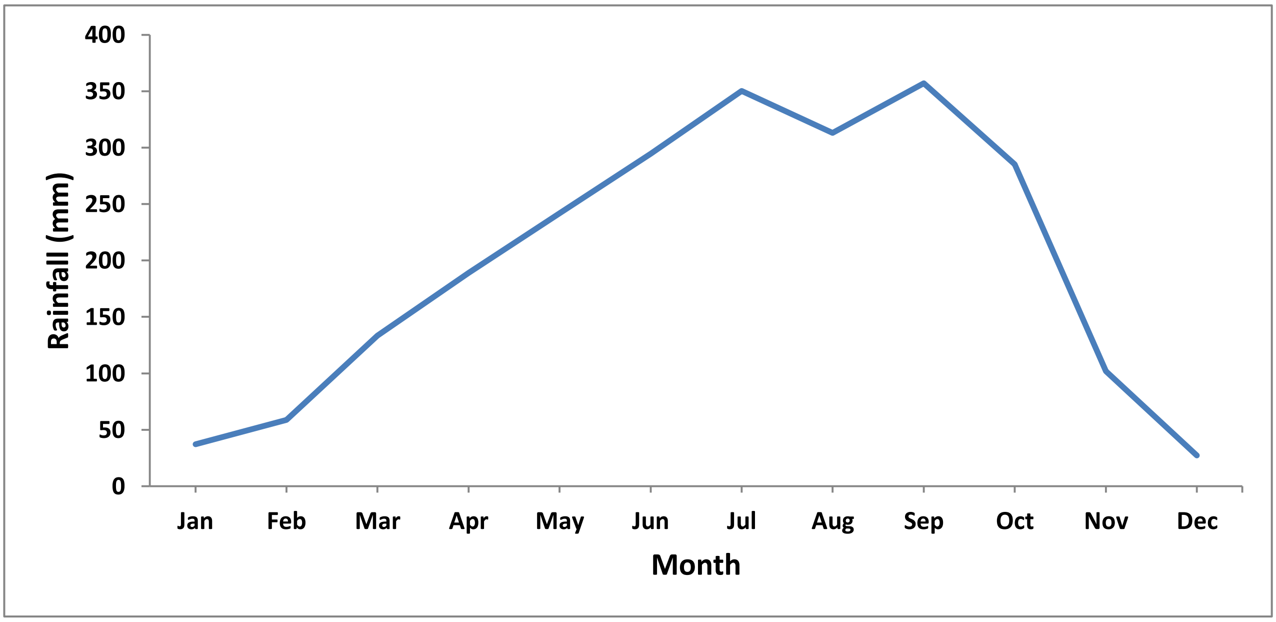

Figure 2.6. Average monthly precipitation of the Niger Delta (Data source: the Nigerian Meteorological Services 1980-2010).

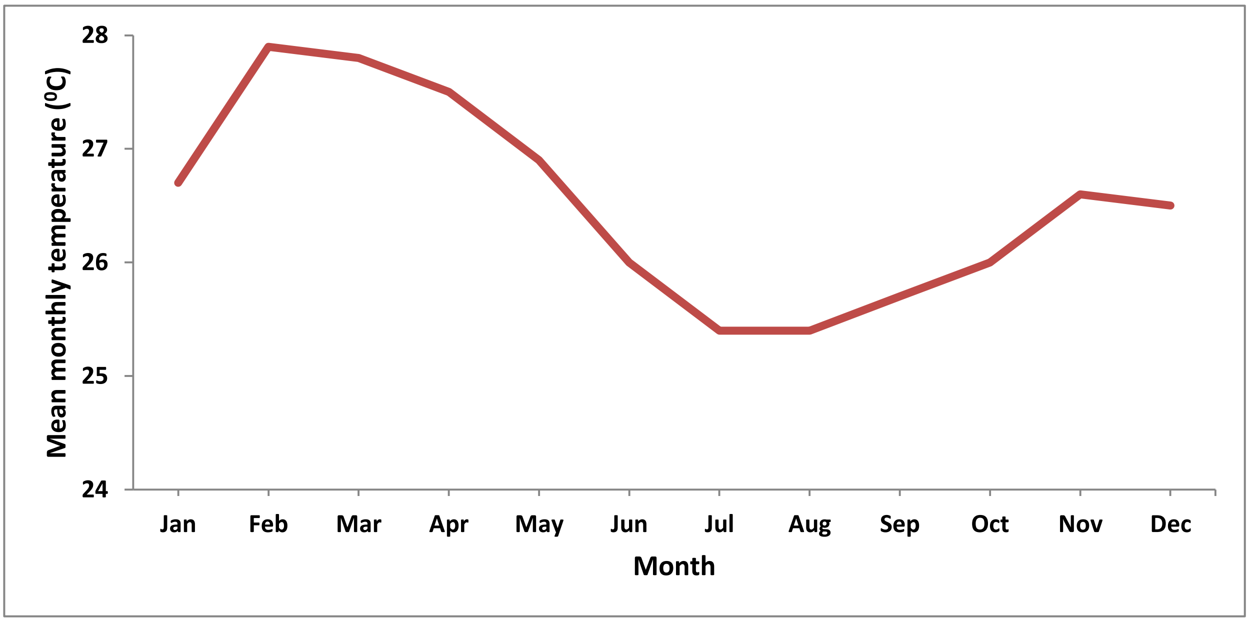

Figure 2.7. Mean monthly temperature of the Niger Delta (Data source: the Nigerian Meteorological Services 1980-2010).

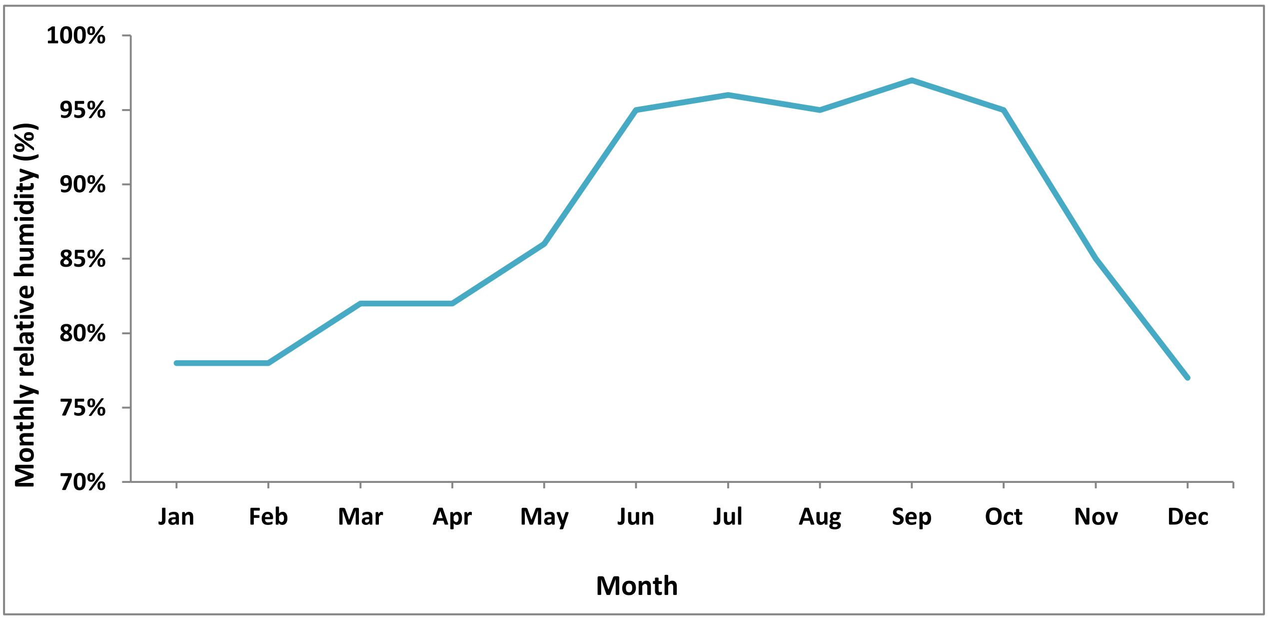

Figure 2.8. Monthly relative humidity of the Niger Delta (Data source: the Nigerian Meteorological Services 1980-2010).

2.4. Ecology Zones of the Niger Delta

It is evident from previous studies that the Niger Delta region is very rich in biodiversity (NDES 1997; Phil-Eze 2001; Were 2001; 2009; NDDC 2004; Phil-Eze and Okoro 2008). What is pertinent from literature is that the ecology of the Niger Delta is characterised by a variety of vegetation that varies according to the environmental and geomorphological parameters already discussed above. Protection of the ecological resources of the Delta is necessary for maintenance of this biodiversity. In developing a framework towards reduction of environmental degradation and conservation of biodiversity, it is imperative that we have an understanding of the ecology in the Delta and its role in the development of the country.

Several ecological maps of Niger Delta exist in the literature. Although, the majority of these studies capture only part of the region that is relevant to this study. Out of all ecological maps evaluated, the one developed by NDRDMP (2006) and Blench (2007) were found to be most useful, although, their coverage and classification varied (Figures 2.9a & b). The major difference between these maps is that the NDRDMP (2006) identified five major ecological zones (Rainforest, Mangrove, Freshwater Swamps, Mountain Region and Derived Savannah) while Blench (2007) recognised six ecological zones (Rainforest, Mangrove, Flood Forest Zone, Eastern Flank, Marsh Forest Zone and Barrier Islands). Barrier Islands were not identified in NDRDMP (2006), while Mountain Region was not included in Blench (2007). Though Blench suggested additional zones which are called "Eastern Flanks and Marsh (Deltaic) Forest Zones" (Figure 2.9b). Furthermore, the map by NDRDMP does not show detailed information about freshwater swamp forest at the centre of the map (Figure 2.9a). Thus, a new map has been developed by combining these two maps.

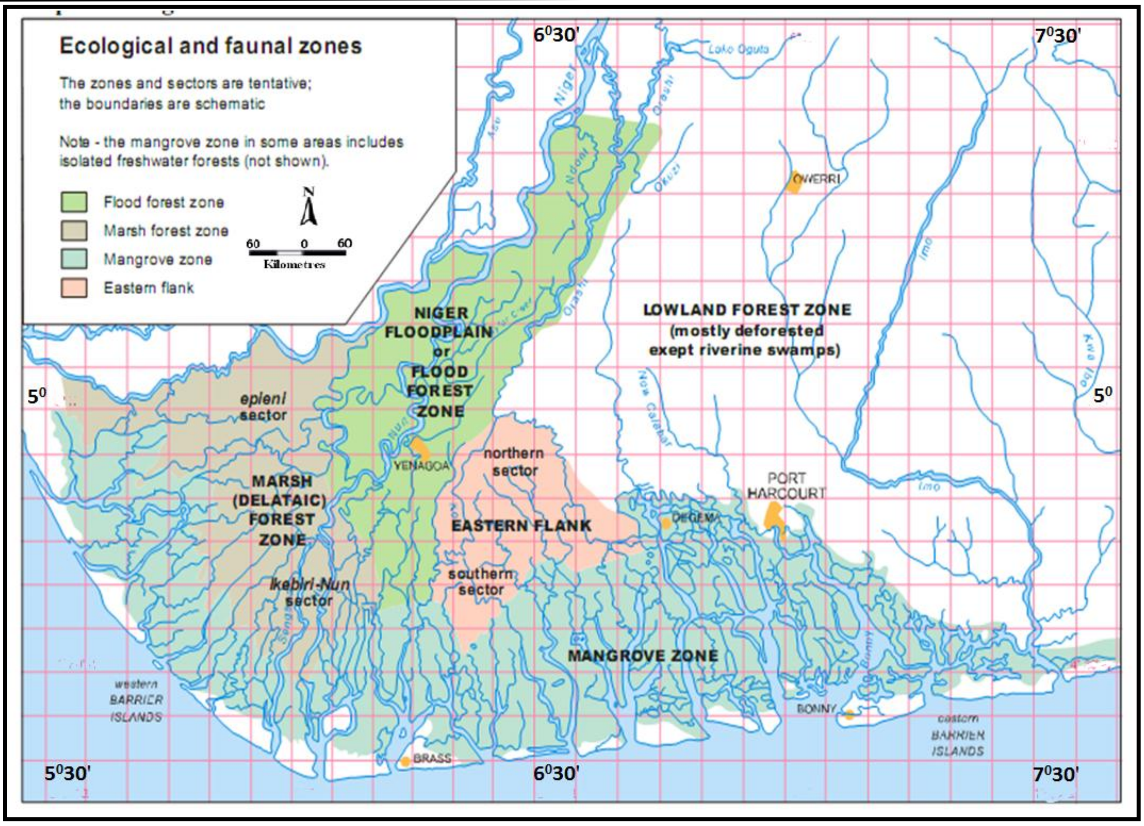

Figure 2.9a. Ecological zones of the Niger Delta (modified from Blench 2007).

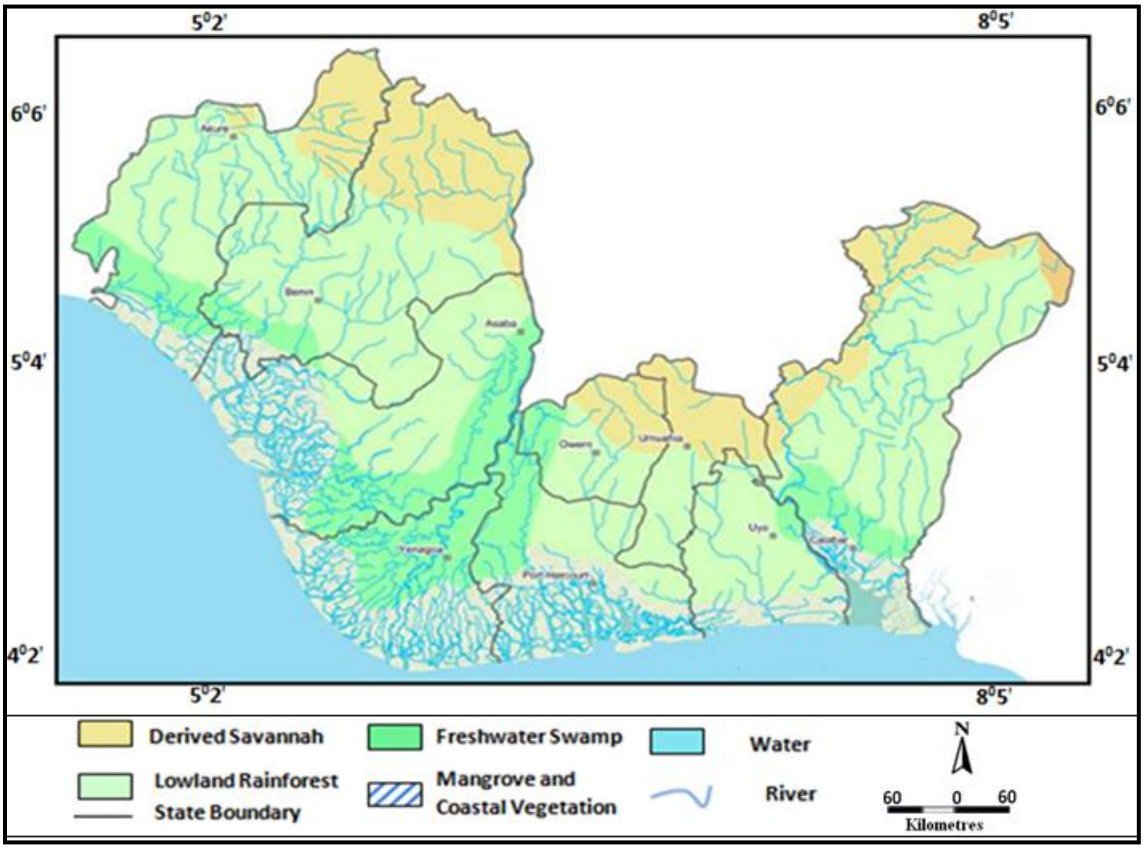

Figure 2.9b. Ecological zones of the Niger Delta (modified from NDRDMP 2006)

In the new map (Figure 2.9c), the Eastern Flank and Marsh (Deltaic) Forest Zone are combined with Freshwater Swamp forest since they are annex of freshwater swamp and both have the same ecological characteristics with similar species of trees. The Barrier Islands are combined with mangrove, because studies have shown that the majority of plants in Barrier Islands are mangrove plants (NDRDMP 2006). Also, the present study combines Derived Savannah and Mountain Region (as in NDRDMP) with Rainforest, since these classes were at some time in the past forest, but have been degraded due to human activities. The natures of these different ecological zones are discussed below.

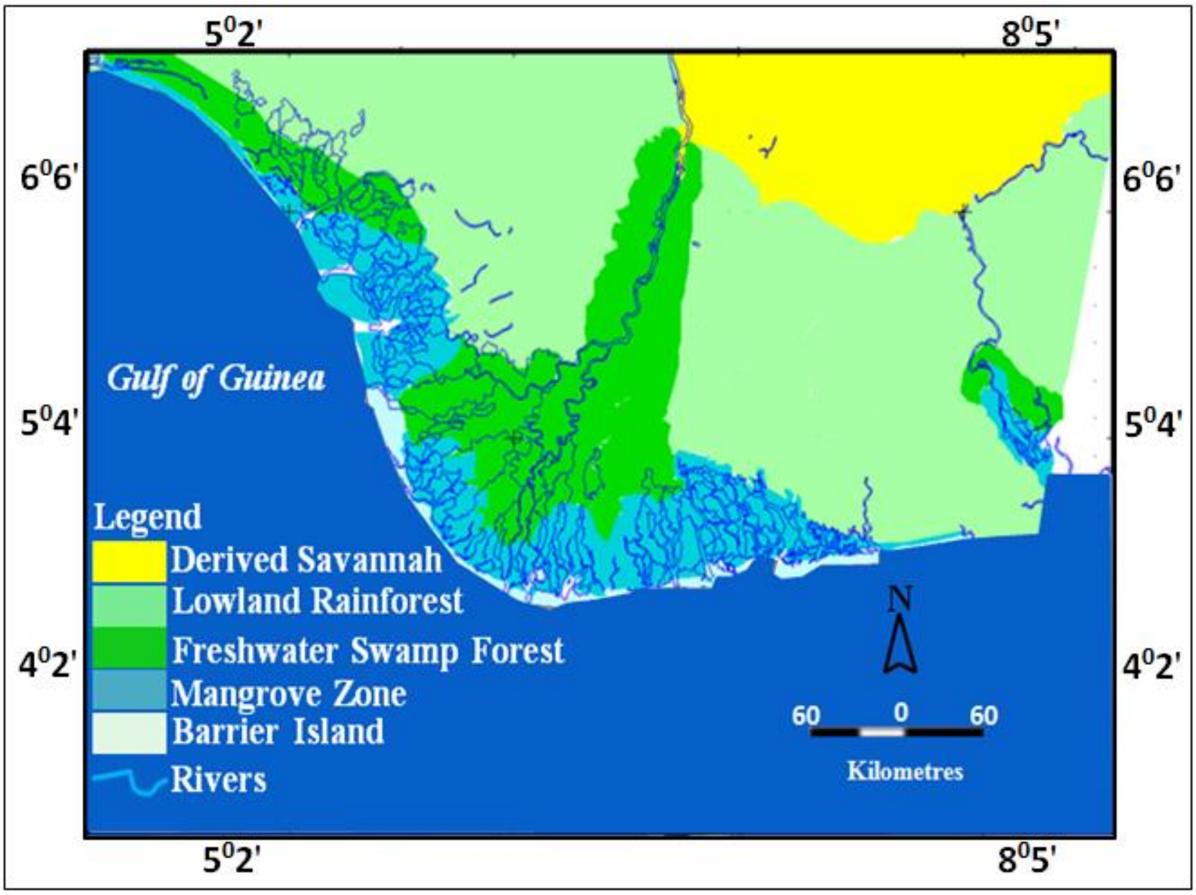

Figure 2.9c. Ecological zones of the Niger Delta, derived from both maps 2.9a and 2.9b and used throughout this study.

2.4.1. Mangrove Ecological Zone

Mangrove vegetation covers the coastal region of the Niger Delta (Figure 2.10), along the brackish lagoons and rivers systems. The region consists of third largest mangrove in the world and largest mangrove forest in Africa (Ebeku 2006; Uyigue and Agho 2007). The dominant mangroves are Red Mangroves (*Rhizophoraceae*) and White Mangroves (*Avicenneaceae*), which form more than 90% of the vegetation in the mangrove zone (Nest 1991; NDDC 2001; Were 2001). The Red Mangrove species *Rhizophora racemosa* is the pioneer species, followed by *R. harrisonii and R. mangle,* which thrive as the land gets drier and salinity decreases (Wilcok and Powell 1985; Were 1991). The White Mangrove occurs sparsely amongst the Red Mangroves and thrives in less water logged areas (Were 2001). A report by NDDC (2001) states that mangrove vegetation zone protects the Delta against the influx of tidal saline waters.

Figure 2.10. A photo of a mangrove forest in the Niger Delta (Photo courtesy: NDRDMP 2006).

Mangroves provide important ecological services in the region (Table 2.1). They are source of medicine, timber and other resources to indigenous people and remain important for the various organisms that live in the ecosystem. A study by NEST (1991) noted that:

> *“Red Mangrove* Rhizophora racemosa *is the most exploited species and is used for firewood, poles and timber. The numerous roots as well as stumps are used locally for the preparation of salt. The bark of the tree provides a cheap source of tannin for dyeing cloths and leather. The mangroves provide breeding and nursery grounds for many commercially important species of fish and shell fish. The tilt roots of the mangroves and mud surface usually support a varied fauna of oysters, crabs and other invertebrates”.*

2.4.2. Freshwater Swamp Forest Ecological Zone

The freshwater swamp forest is subject to the silt-laden fresh water of the Niger River and is a rich timber resource in the Delta. This zone also has a very high fishery and agricultural potential (NDDC 2001). It is generally characterised by tall trees such as *Musanga cecropioides*, *Annona senegalensis*, *Anthocliesta vogelii*, *Elieas guineansis*, *Harungana madagascariensis* and *Tectonia grandis*, the majority of which are used as commercial timber (Sorgwe 1997; Agbagwa and Ekeke 2011). These plants are useful sources of timber for various constructions, stake pole production of fish traps, boat carving, fishing platforms as well as shoreline protection (Table 2.1). Also there are other important swamps and aquatic plants such as *Nymphaea*, *Jussiaea,* shrubs such as *Juncus sp, Pandanus sp, Raphia hookeri, R. vinifera* (Sorgwe 1997; NDDC 2001; Blench 2007), which are useful for local medicine. The freshwater ecological forest still has a low deforestation rate compared with other forest ecological zones, because the forest zone is inundated by rivers and annual Delta flooding, which makes access difficult. This water-logging also permits little urban expansion and also makes the land unsuitable for agricultural purposes (NDRDMP 2006). Though a recent study by Mmom and Arokoyu (2010) reported that because of high demand for trees from this forest, selective forest removal for commercial timber and firewood has been the foremost degradation issue in freshwater swamp zone in recent years.

Table 2.1. Notable tree species in the ecological types of the Niger Delta

Ecological types	Notable tree species	Utility
Mangrove	*Rhizophora racemosa, R. harrisonii, R. mangle, Avicennia africana, Laguncularia racemosa* and *Conocarpus erectus.*	Firewood, poles, traditional medicine and timber.
Freshwater swamp	*Musanga cecropioides, Annona senegalensis, Anthocliesta vogelii, Elieas guineansis, Harungana madagascariensis, Tectonia grandis, Nymphaea sp, Jussiaea sp, Juncus sp, Pandanus sp, Raphia hookeri* and *R. Vinifera.*	Firewood, stake pole production, fish traps, timber, boat carving, fishing platforms, shoreline protection and traditional medicine.
Rainforest	*Khaya ivorensis, Guarea thompsonii, Entandophragma cylindricum, Entandrophragma angolense, Guarea cedrata, Lovoa trichilioides, Gossweilerodendron balsamiferum, Milicia excelsa, Terminalia ivorensis, Triplochiton scleroxylon* and *Terminalia superba.*	Timber resources, firewood, sawn wood, particleboard, pulp/paper, poles and traditional medicine.

Figure 2.11. An aerial photo view of a freshwater swamp in the Niger Delta (Photo courtesy: NDRDMP 2006).

2.4.3. Rainforest Ecological Zone

Rainforest is the most complex in terms of species diversity. According to Nest (1991), the forest reserve covers about 10% of the Niger Delta with the average tree height being about 20-25m. In this zone, four major vegetation strata are recognised in areas of unmodified rainforest (Figure 2.12). The uppermost stratum which is a layer of dense forest called Selva, comprises of tall trees (of about 40-50 metres tall), with smooth bark. Trees in this category include the Iroko and Mahoganies (Nzewunwa 1980). Attached to most of these trees species are epiphytes and lianas (Figure 2.12). The second stratum is the combination of varieties of trees which are 20 to 35 metres high. This consists of a canopy formed by high branches of tall trees providing shade for lower layers. The third, which is an intermediate layer of shorter trees, consists of smaller trees up to 20 metres. The fourth layer consists of association of small stemmed shrubs, mosses, ferns, lichens and herbs. The economically important African Mahogany family (Meliaceae) is well represented in this zone which includes: *Khaya* *ivorensis, Guarea thompsonii, Entandophragma cylindricum, Entandrophragma angolense, Guarea cedrata*, and *Lovoa trichilioides* (Table 2.1). Other economically important timber species include *Gossweilerodendron, Milicia excelsa, Terminalia ivorensis, Triplochiton scleroxylon* and *Terminalia superba* (Ebeku 2006, NDRDMP 2006).

Derived savannah is found in the northern parts of the Niger Delta. It comprises savannah type grasses and shrub, with a few scattered trees. It is believed that what is known as derived savannah today, was once a secondary rainforest, but has been reduced to open woodland as a result of clearing of rainforest for agricultural activities. Due to constant human pressure, it is virtually impossible for trees to grow to maturity in this zone (Figure 2.13). Thus in the Niger Delta, the derived savannah vegetation is a reflection of forest clearance. Major agricultural systems in rainforest and derived savannah include permanent cultivation and shifting cultivation which involves rotational bush fallowing; agro-forestry and livestock production. But, the problem of land shortage, as a result of demand for land by rapid population growth has drastically reduced the amount of cultivable land. Thus, farmers have consequently reduced the fallow period to 1-3 years. In some cases, continuous farming is being practised (Iyayi 2004 and Jike 2004).

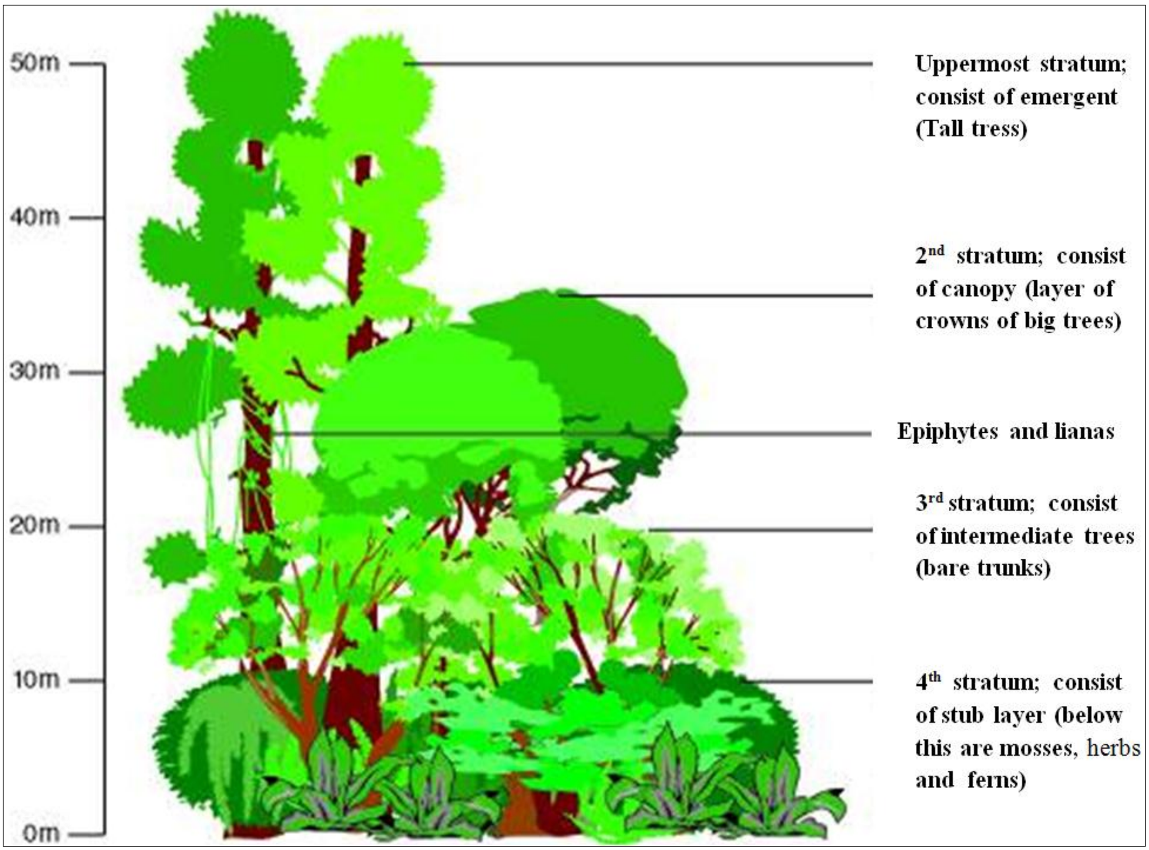

Figure 2.12. The different layers of vegetation in the rainforest zone (Source: Hutchinson encyclopaedia)

Figure 2.13. A photo of a derived savannah in the Niger Delta (Photo courtesy: NDRDMP 2006).

2.5. Deforestation of Niger Delta and Degradation of Forest Reserves/Protected Areas

Though, the Niger Delta region is very rich in biodiversity, what is evident from literature is that the ecology of the Delta has been under pressure for some times. Deforestation and environmental degradation have increased throughout the Niger Delta region, but its impacts are being felt most in rural regions, where the majority of people depend on ecological resources for their sustenance and future prosperity. For instance, a study by Were (2009) estimated that about 50% of mangrove vegetation in the Niger Delta has been lost as a result of deforestation and indiscriminate logging by local inhabitants. Deforestation is a general environmental problem in the region, cutting across all geopolitical states. For example in Bayelsa State alone, Ibaba (2010) noted that the state loses 200,000 trees annually, this is about 3% of the forest. In another study, it is stated that over 200,000 poles and wooden items such as logs or billets have been extracted from the mangrove in the Niger Delta by inhabitants between 1970 and 1989 (Adegbehin and Nwaigbo 1990).

Other recent studies have reported that utilization of forest resource has resulted in depletion in many of the protected areas in the Niger Delta during the past few decades (Kalu and Izekor 2006; Mmom and Arokoyu 2010; Alabi 2012). Studies by Ite (2001; 2005) revealed that forest reserves and protected areas in the Delta have been degraded without any enforcement of conservation measures. This has led to depletion of natural vegetation, habitat loss for wild animals and plants, loss of genetic resources and perhaps endemic species which are not yet identified (USAID 2008). There are many forest reserves/protected areas in the Niger Delta, a number which were established in 1896, when forestry began officially in Nigeria with the head office in the protectorate of Lagos (Lowe 2000).

Protected areas in the Niger Delta can be classified into three major categories: forest reserves; national parks and game reserves; and traditional-use conservation areas (NDRDMP 2006). Out of 966 registered forest reserves in Nigeria, over 70 are found in the Niger Delta region (Oates 1995; 2005; NDRDMP 2006). The majority of these forest reserves are under the control of Nigeria Forest Department of Federal Ministry of Environment and State forest departments (Amusa 2003; Ebeku 2006). Although there is little information about national parks and game reserves located in the Niger Delta, but a study by USAID (2008) has reported several protected areas in the Niger Delta, with a list of the major animal species and the main cause of biodiversity loss (Table 2.2). Out of over 40 wildlife reserves registered in Nigeria, seven game reserves and two national parks are located in the Niger Delta (NDRDMP 2006). The majority of these areas are under pronounced pressure of deforestation resulting from many factors that are discussed in the next section (Table 2.2).

Table 2.2. Major protected areas (PAs) in the Niger Delta (Source: USAID/Nigeria, 2008).

Protected Area	Ecological Zone	Major Species	Major Causes of Biodiversity Loss
Name: Okomu National Park **Location:** Edo State **Year Gazetted:** 1999 **Status:** National park (Federal Government) **Official size:** 1124 km^2	Tropical Rainforest	White-throated, monkey, forest elephant, and African buffalo.	Illegal logging. Uncontrolled increase in population of the fourty-five (45) villages around the park.
Name: Cross River National Park **Location:** Cross River State **Year Gazetted:** 1991 **Status:** National park (Federal Government) **Official size:** 4,000 km^2	Tropical Rainforest	Cross River gorilla, drill monkey, chimpanzee, preuss' guenon, red colobus monkey, sclater's guenon, angwantibo, grey-necked picathartes and xavier's greenbul.	Large-scale illegal logging and clearing of forest for plantation agriculture and farmlands. Uncontrolled hunting of wildlife, insufficient funding for park protection and monitoring activities. Continuous increase in the population of the six enclave communities and that of other communities that surround the park.
Name: Afi Mountain Wildlife Sanctuary **Location:** Cross River State **Year Gazetted:** 2000 **Status:** Wildlife sanctuary (State Government)	Tropical Rainforest	Cross River gorilla, drill monkey, chimpanzee, angwantibo, and grey-necked picathartes.	Illegal logging and clearing of forest for agriculture. Unsustainable hunting of wildlife. Inadequate funding of sanctuary. Protection and monitoring activities. Rapid increase in

Official size: 100 km^2			population of communities around the sanctuary that has resulted in uncontrolled encroachment into it.
Name: Obudu Plateau **Location:** Cross River State **Year Gazetted:** Nil **Status:** Community land/State Forestry Commission **Official size:** 400 km^2	Escarpment Forest and Montane Grasslands	Preuss' guenon, white-throated mountain babbler, green-breasted mountain bush shrike, and bannerman's weaver.	Rangeland burning by nomadic pastorialists. Unsustainable firewood collection for cooking and warming homes. Forest clearing for farming. Forest clearing for establishment of new settlements. Erosion due to loss of vegetation cover on steep slopes.
Name: Mbe Mountain **Location:** Cross River State **Year Gazetted:** Nil **Status:** Community Land/State Forestry Commission **Official size:** 10, 000 hectares	Tropical Rainforest	Cross River gorilla, red-eared monkey, chimpanzee, grey-necked picathartes and drill.	Large-scale illegal logging and clearing of forest for plantation agriculture and farmlands. Uncontrolled hunting of wildlife. Poorly organized and funded protection and monitoring activities by community-based organization. Rapid increase in population of communities around the sanctuary has resulted in uncontrolled encroachment into the sanctuary.
Name: Ebok Kabaken **Location:** Cross River State **Year Gazetted:** 2000 **Status:** Community land **Official size:** Uncertain	Grassland surrounded by forest	Over 1 million European Barn Swallows use the site as winter roost. Other uncommon bird species that have been recorded here include chestnut, red- cheeked wattle-eyes, blue-headed wood dove, chocolate-backed	Clearing of the grasslands for farming. Local people hunted the swallows for food, and 100,000 to 200,000 birds were estimated to have been caught annually.

		kingfisher, red-rumped tinkerbird, and red-tailed bristlebill.	
Name: Apoi Creek Forest **Location:** Bayelsa State **Year Gazetted:** 2008 **Status:** Forest reserve (state government); Ramsar Site no. 1751 **Official size:** 29,213 hectares	Tidal Freshwater, Swamp forest composed mainly of marshes, mangrove forests and fresh water swamps	Red colobus monkey and sclater's guenon.	Selective logging. Digging of canals for transport of timber.
Name: Oguta Lake **Location:** Imo State **Year Gazetted:** 2008 **Status:** Community Ramsar Site no.1757 **Official size:** 572 hectares	Freshwater lake surrounded by swamp forest.	The lake contains 258 species of phytoplankton in 107 general and 40 fish species. Small scattered populations of the endangered sclater's guenon occur in some relict forests south of the lake.	Overfishing is stressing the lake and sewage and sedimentation aided by deforestation are threats.
Name: Upper Orashi Forests **Location:** Rivers State **Year Gazetted:** 2008 **Status:** Forest reserve (State Government); Ramsar Site no. 1759 **Official size:** 25,165 hectares	Fresh water swamp forest	Home to the critically endangered Sclater's guenon and endangered white-throated guenon, red colobus monkey and heslop's pygmy hippopotamus. the site is a roost for the African grey parrot and also hosts a significant number of Water Bird species.	Non-implementation of the sites management plan, ethnic militancy, insecurity, poaching and uncontrolled logging.

Using Okomu as a case study, Oates (1995) reported several failures and unrealistic forest policies practiced ever since the establishment of Okomu. Perhaps, the best example being the "Taungya System" introduced in 1945 (Oates 1995). The taungya system is an agro-forestry method of forest management whereby part of forest reserve is initially allocated for planting food crop, and seedling of tree species planted on the same farm plots, in order to regenerate forest to a harvestable stand of timber (Menzies 1988; Hellermann 2007). The Taungya system has been practised in many countries in Africa and China since it was developed by the British in Burma in 1856 (Menzies 1988).

Oates (1995) also noted that although forest reserve land was allocated under this system to migrant farmers in Okomu for the purpose of forest regeneration, no trees were planted; rather the system degenerated into shifting cultivation farming which eventually leads to deforestation. The taungya system focused primarily on forest protection and agricultural development assistance to migrant farmers who were allowed to settle in Okomu. The introduction of the taungya system within forestry reserves initially played a significant role in addressing issues of food requirements for hungry migrant farmers in Nigeria (Phil-Eze and Okoro 2008; Awotoye *et al*. 2009). However, studies by Oates (1995), Ite (2001) and Kalu and Izekor (2006) have shown how the system has been a disaster for environmental protection. Oates (1995) noted further that deforestation rates increased due to the fact that part of forest were let to migrant farmers, leading to increased settlement, expansion of agricultural land use and wildlife poaching within the areas of forest that remained. By 1990, government enforced a tougher policy towards effective control of poaching to the extent that over sixty (60) Igbo migrant families were reported to have left (Oates 1995; Ite 2001). Nonetheless, degradation in Okomu has accelerated, as part of the forest has been allocated by government to the Iyiyi Group of Companies for rubber and oil palm plantations and there are reports that the company also engages in the unlawful removal of timber trees in Okomu (Coastal News 11 July 2010, Adekunbi 2011).

Studies have reported similar scenarios in other forest reserves in the Delta. For example, Kalu and Izekor (2006) showed that in Edo State, deforestation within forest reserves resulting from commercial logging and the taungya system accounted for 74% of forest logging over the period of study. Ite and Adams (1998) also estimated the deforestation rate within Cross River State to be 0.6% per year. Likewise, a recent study by Onojeghuo and Blackburn (2011) estimated a similar annual rate of deforestation for the entire Delta to be 0.95% per year. These studies also noted that many species in the forests are disappearing because they are being harvested beyond their capacity to regenerate. It has been estimated that nearly ten (10) species became extinct in the region every year due to the rapid deforestation (Phil-Eze and Okoro 2008).

2.6. Animal Biodiversity and Conservation Challenges in the Delta

Degradation and destruction of forest have great impacts on the animal biodiversity in the Niger Delta affecting, for example, large mammal biodiversity such as chimpanzee; monkeys; antelopes; pygmy hippopotamus; spotted genet; black squirrel; elephant; leopard and black pig (Ite 2001; Baker and Olubode 2007; Greengrass 2009). Degradation of forest has two implications on wildlife: Firstly, removal of trees and clearing of forest reserves for other human purposes, which as discussed above, reduces the area of habitat for wildlife. Secondly, forest degradation also gives opportunities for hunting the remaining animals.

2.6.1. Biodiversity Loss Resulting from Hunting

Hunting for wildlife is a common traditional practise among the villagers of the Delta. In many of forest reserves in the Niger Delta, both primitive and modern hunting tools are currently employed to catch animals. Dogs, snare traps, spears, poisoned baits, bows and arrows are sometime used in traditional group hunting, while nowadays, animals are more commonly hunted by gun. A significant portion of the animal protein consumed by those living in the rural communities around the Delta is meat ("Bush meat") from wildlife (Amusa 2003). Studies by Orhiere (1992) and Akinsorotan *et al.* (2011) have also shown that some parts of animal body are also used in traditional medicine, which form part of health care delivery for rural communities in the region. Morakinyo and Tooze (2007) have reported that the major problem is that many rural communities surrounding forest reserves are traditional hunting and farming groups, who see the forest reserves as hunting grounds (Babalola 2009, Ajake and Anyandike 2012). As a result, many animals are endangered in the Niger Delta.

Figure 2.14 illustrates the distribution of endemic and endangered biodiversity in the region. Endangered animals are now restricted to a few reserve in different parts of the Delta. For example, Red Collobus Monkey and Sclater's Guenon are found in forest reserves within the freshwater swamp zone while Chimpanzee are found predominantly in protected areas along western part of the Delta. The majority of these species are threatened due to deforestation and hunting (Grubb and Powell 1999; Hilton-Taylor 2000; Baker and Olubode 2007).

Studies by RPI/NNPC (1985), Omokhua and Koyejo (2008), Okafor (2010) and Fagade 2010) have reported that the most endangered species in the Niger Delta are Manatees (*Trichechus senegalensis*), Sclater's Guenon (*Cercopithecus sclateri*), the Niger Delta Red Colobus (*Procolobus badius epieni*) and the Niger Delta Pygmy Hippopotamus *(Choeropsis liberiensis)*, while the African Elephant (*Loxodonta africana*), Chimpanzee (*Pan troglodytes*), White-Throated Guenon, and Crested Genet (*Genetta cristata*) are classified as endangered (Grubb and Powell 1999; Were 2001; 2009). For example, the literature records of Niger Delta Pygmy Hippopotamus suggest the species is manly located along the boundary between rainforest and freshwater swamp forest of the Niger Delta, as obvious in Figure 2.14 (Blench 2007; UNEP-WCMC 2007; Were 2009). The two major forest reserves where Pygmy Hippos have been reported in the past are Egbedi Creek and Upper Orashi Forest Reserve (UNEP-WCMC 2007, Blench 2007). The major concern of these studies has been the regular disturbance from forest degradation, selective logging (especially in the Upper Orashi Forest Reserve) and hunting in the reserves. Indeed, as no one has reported a sighting of Pigmy Hippo for many years, the species is probably extinct.

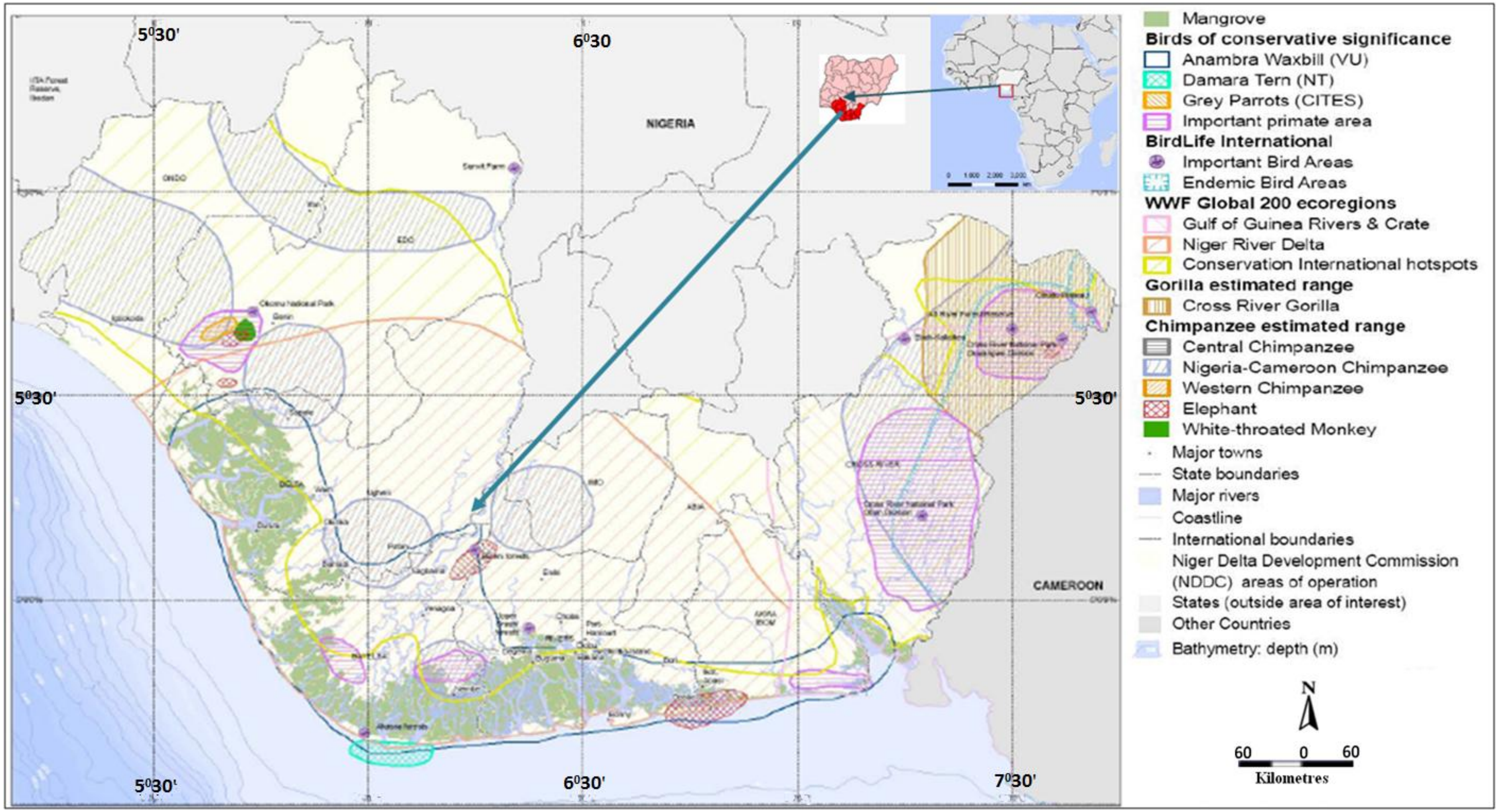

Figure 2.14. Map of the Niger Delta showing biodiversity distribution (Modified after UNEP-WCMC 2007).

2.6.2. Conservation Efforts in the Delta

There are many protected areas in the Niger Delta region with different biodiversity conservation potential (as discussed above), yet there is no serious effort on ground by the government to legally enforce conservation of biodiversity (Ezebilo 2010; Bown *et al.* 2011). To overcome this in recent years, a leading conservation group in Nigeria, Nigerian Conservation Foundation (NCF), with the support of the Chevron Nigeria Limited, are working towards establishing the Niger Delta Conservation Centre. The main aim of this establishment is to encourage conservation in forest reserves/protected areas and reduction of environmental challenges facing the region.

The Nigerian constitution makes provision for protection of forest reserves. For example, section 20 of the constitution of the Federal Republic of Nigeria makes provision for forest resources by stating that its aim is "*to protect and improve the environment and safeguard the water, air, land, forest and wildlife*". Nonetheless, many studies (e.g. Ite 1996; 2001; Luiselli and Akanni 2003) have revealed that the implementation of conservation policies is poor, and there are no attempts to gain the support of local people who live close to the forest reserves. Blom (2004) estimated the cost of effective conservation in the Niger Delta, and found out that over $87 million per year would be needed for over a 10-year investment. The managers of forest reserves (both at federal, state and local levels), were found to be incapable of enforcing the laws guiding the exploitation of forest reserve resources. The main obstacle against the enforcement of laws is lack of adequate manpower (Ezebilo and Mattsson 2010), insufficient funding, technology and logistics (Ezebilo 2010). As a result of this management gap, community forest management institutions and local conservation initiatives could have a significant influence on forest conservation, rather than governmental and non-governmental organisations (Ajeke 2012). It is obvious from the study by Blom (2004) that conservation projects are capital intensive, thus effective conservation management calls for support from local communities, government and NGOs.

2.7. What are the Drivers of deforestation in the Niger Delta?

Previous studies argued that the increase in oil production areas is a major factor of deforestation and other environmental degradation in the Niger Delta (Morakinyo and Tooze 2007; Babatunde 2010; Omorovie 2012; Iwegbue *et al.* 2012). The majority of these studies identified lying seismic, canal construction and other pollutions from oil production as the main ecological destruction forest in the Delta (See Section 2.5.3). It became clear from this literature review that not all of the deforestations and changes in landuse are linked to the oil and gas production. Despite the impacts of oil production on the region, other studies have shown that pressure from increasing population and associated demand for forest resources, commercial and local selective logging, and agricultural activities have played a much larger role in changing the environment in the region (Eregha and Irughe 2009; Mmom and Arokoyu 2010). Thus, the main aim of this section is to evaluate the various drivers of deforestation and landuse change in the Niger Delta.

2.7.1. Rapid Population Increase and Urbanisation in the Delta

Several studies have reported that an increase in population and rapid urbanisation has had negative impacts on the Delta environment (Obire and Amusan 2003; Aaron 2006; Godstime et.*al*. 2007; Morakinyo and Tooze 2007; Blench and Morakinyo 2013). There was no officially accepted census before 1953, though several estimations have been made in times past. The first national census was in 1952-53, with the total population for all Nigeria put at 31.6 Million. It is impossible to know the population figure for Niger Delta in the 1952-53 census results. This is because what is known as Niger Delta today is combination of communities under different provinces during the colonial rule. This census is now considered an underestimation, due primarily to logistical problems in reaching majority of people in remote areas and inadequate training of enumerators. Many ineffective attempts have been made since and until the 1963 census, that estimated a total population of Nigeria to be 55.6 Million, and which was officially accepted (Makama 2006). The probable rapid rise in population between 1953 and 1963 (from 31.6 Million people in 1953 to 55.6 Million people in 1963), might be due to the introduction of oil production in the Delta region. From 1963 to the 1991 census, national population estimates were based on projections from the 1963 census (Bamgbose 2009). The 1991 census was followed by the one in 2006, and data showed a rapid increase in the population of the Niger Delta. The total population in 1991 was about 20 million, which was about 23% of Nigeria's total population. This increased to 28 Million in 2006 (Figure 2.15). NPC estimated that population of the Niger Delta region would be nearly 33 million people by the end of 2013 (NPC 2006).

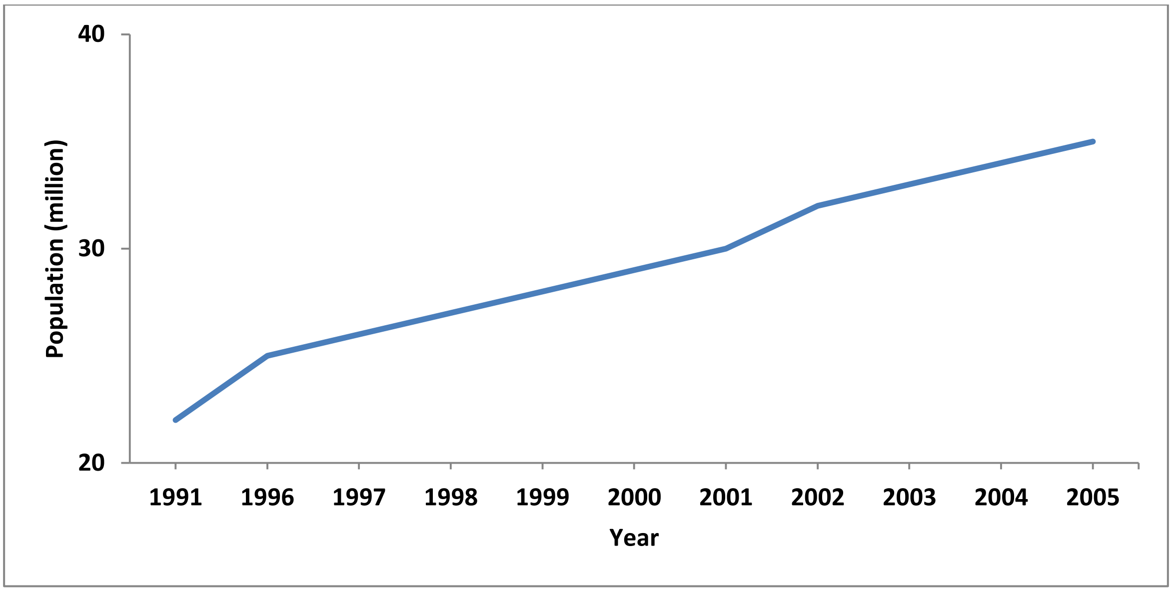

Figure 2.15. Niger Delta population trend: 1990 to 2006 (Data source: Nigeria Census, 2006).

The census shows that the Delta region has the highest population density in the country. A report by NPC (2006) estimated a population density in the Delta to be 450 persons per km^2, making the region the most densely populated region in Africa. The highest population density is found in the rainforest, while the mangrove zone has a lower population density (NDRDMP 2006). Earlier studies have reported that the major factor of population increase in the Niger Delta region might be because of a high rate migration into the Delta region by people from other parts of Nigeria, who were searching for employment in the oil industry (Ebeku 2006; Amnest 2009; Eregha and Irughe 2009; Eregha and Irughe 2009). The majority of the population in the region (about 90%) depend solely on agriculture and forest material for fuel (Ibaba 2010; Mmom and Arokoyu 2010). This may explain the high rate of deforestation outlined in Section 2.7.2.

Urbanization is one of the many ways in which humans are altering the Niger Delta environment. Rapid urbanization resulting from oil industrialization is one of the important factors for both social and economic developments of the Niger Delta, and is also responsible for environmental changes in the region. On the other hand, some studies have claimed that rural-urban migration is a major driver of urban growth in the Delta (Oates 1995; NDRDMP 2006; Bamgbose 2009). For example, NDRDMP reported that the rate of rural-urban migration is about of 5.3% per annum in the Niger Delta (NDRDMP 2006). The population growth rate of about 3.1%, based on last population census, suggests that there has been a remarkable growth in urban populations that has resulted in rapid urbanization (AAS 1999; NDDC, 2006). These factors have led to an increase in the population of major cities by nearly 40% between 1991 and 2006. Taking Port Harcourt and Warri as examples, in 1960, the population of Port Harcourt and Warri were 179,563 and 55,254 respectively. In 1991, their population were 440, 399 and 326, 643 respectively (NPC Report, 2006). Rapid urban expansion and increase in population density of major cities in the Niger Delta have had serious consequences, such as environmental degradation; overcrowding; poor sanitation and increase in the spread of communicable diseases (Ebeku 2006).

2.7.2. Commercial/Selective Logging, Firewood Collection and Clearing of the Forest for Agricultural Purposes

Commercial logging activities have resulted in a rapid reduction in forest timber in the Niger Delta (Figure 2.16). There are over five hundred (500) sawmills in the Delta region. For example, Sapele, a town in Delta State, has over 70 sawmills and it is the major centre of timber trade. It has the biggest wood industry in Nigeria and wood products being produced include veneer and plywood. Timber is sawn in Sapele, not only to meet the demand in the community, but also to meet construction purposes in nearby cities of Warri, Port Haircut and Lagos (Uyigue and Agho 2007). Many of forest loggers in the Niger Delta practice selective logging, whereby matured indigenous forest tree species are utilized as a source of timber. Most of these studies reported that selective logging is frequent in rainforest, though it also occurs in mangrove and freshwater swamp ecological zones. As a result, very few areas of primary forest remain in the Niger Delta. In addition, trees that are not good timber resource are used for stake poles, production of fish traps, boat carving, fishing platforms and shoreline protection. Studies by Mmom and Arokoyu (2010) and Adekunbi (2011) further reported similar scenarios that the swamp forest in the Delta is being selectively logged and the logs floated out down the rivers, and then up the coast to Lagos, which may well further explain the increase in forest degradation in the Niger Delta.

Clearing of the forest for agricultural purposes is another severe environmental problem. Most communities in the region are agrarian societies, who apply bush burning to clear their farms during the dry season, for easy planting in wet season. Agriculture lands are main sources of living for the rural people in the Niger Delta (Okali and Eleri 2004). Farming practices in the Delta are largely subsistence system and shifting cultivation, using slash-and-burn to prepare the land. The percentage of land under cultivation ranges from 75.5% in Akwa Ibom, to 46.9% in Delta, and 30% in Rivers and Bayelsa States. The increasing population of farmers leads to agricultural expansion, and thus, agriculture can encroach into forest. As a result, many forested areas are largely cleared for agriculture, leading to increase in farm, a mosaic of cropped and fallow areas with many oil palm plantations.

Figure 2.16. Logging in the Niger Delta (Source: photo taken during the field work).

Firewood collection by local people is another factor that promotes forest degradation in the Delta. Cases of fuel wood collection for domestic uses are mostly reported in the literature (Hellermann 2007; Akinsorotan *et.al.* 2011; Adekunbi 2011; Onojeghuo and Blackburn 2011). People in the region depend on forest for firewood, which is the main source of fuel for domestic cooking. This is because many of these people live below one US dollar per day (NDDC 2006). Due to high rate of poverty therefore, many people in the Delta cannot afford kerosene (though they live in a region where this commodity is produced), thus, they are forced to chop down trees for cheap fuel for cooking. Many rural people cut down forest, some for domestic purposes and selling the rest as means of income (Akinsorotan *et.al.* 2011; Adekunbi 2011). However, wood fuel collection for domestic use or as a means of income is contributing to the rapid forest degradation in the Delta region (Figure 2.17). Thus, most of the forest resources of the Niger Delta are declining, either being converted to farmland, degraded by wood fuel collection and logging activities, or by oil exploration.

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Figure 2.17. Use of firewood for cooking (Source: photo taken during the field work).

2.7.3. Oil Production Impacts on the Environment of the Niger Delta

Oil production has played an increasing role in Nigerian's economy since 1960, when oil started to become the main export. Oil production increased rapidly from 46,000 barrels/day (b/d) in 1960 to about 540, 000 b/d in 1969 to over 2,000,000 b/d in 1973. From then on, production did not follow a linear pattern, as seen in Figure 2.18, though the general trend shows an increase. Between 1970 and 1979, Nigeria experienced an increase in oil production to 2,400,000 b/d, while production declined between 1980 and 1983 to nearly 1,400,000 b/d. From late 1990s to 2000s, production began to increase again from 1,950,000 b/d to 2,285,000 b/d. This increase was as a result of foreign oil companies' commitment of substantial investments to extend oil exploration and production activities in Nigeria.

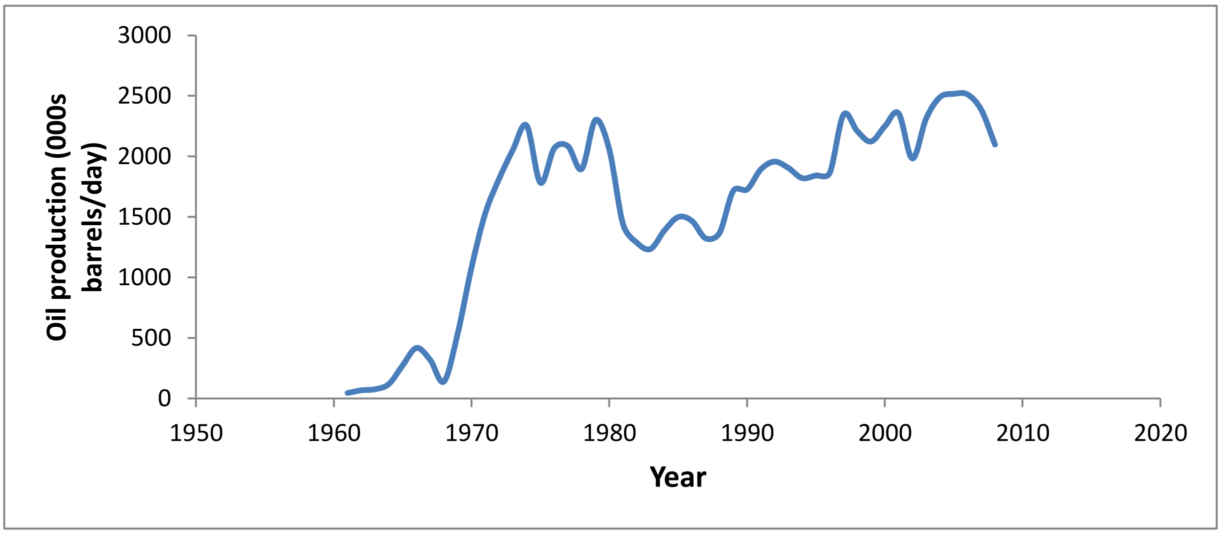


Figure 2.18. Nigerian crude oil production, 1960-2008 (Data source: NNPC annual statistical bulletins, 1997 to 2008).

Many studies have claimed that pollution from oil and gas production constitutes one of the main environmental problems affecting the Niger Delta (Ebeku 2006; UNDP 2006; Ndubusi and Asia 2007; Eregha and Irughe 2009). For example, a report by UNDP (2006) estimated that between 1976 and 2001, over three million barrels of oil were lost in about 6,817 oil spillage incidences, and about 65% of this oil was not recovered (Table 2.3; Figures 2.19 and 2.20), and thus permanently impacted the environment. For example, within Bayelsa and Delta States, a World Bank (1995) report noted 2,300m^3 of oil spill during two hundred and fifty (250) separate incidents. A report by experts, who visited the region in 2006, put the oil spill figure to be over 13 million barrels of oil during the past 50 years (NCF 2006; Amnest 2009).

Table 2.3. Summary of some oil spills in the Niger Delta, 1979-2005. (Data source: NNPC report, United Nations Development Programme (UNDP) and Niger Delta Human Development Report, Abuja, Nigeria).

S/N	Episode	Date	State	Quantity Spilt in barrels
1	Forcados terminal oil spillage	July, 1979	Delta	570,000
2	Funiwa well blow out	Jan, 1980	Rivers	400,000
3	Oyekama oil spillage	May, 1980	Rivers	10,000
4	Warri – Kaduna pipeline rupture at Abudu-Edo	Nov, 1982	Edo	18,000
5	Oshika oil spill	August,1983	Rivers	10,000
6	Idoho oil spill	Jan,1998	Akwa-Ibom	40,000
7	Jones Creek oil spill	Jan, 1998	Delta	21,548
8	Jesse oil spill	Oct, 1998	Delta	10,000
9	Etiama oil spill	May, 2000	Bayelsa	11,000
10	Ughelli oil spill	August, 2005	Delta	10,000
11	Agbada oil spill	Dec, 2003	Rivers	Unknown
12	Ewan oil spill	August, 2004	Ondo	Unknown
13	Diebu Creek Field	2000	Bayelsa	
14	Eket	2000		Unknown
15	Ogbodo	Jan, 2001	Rivers	86, 785
16	Isuikwuato LG (Texaco)	2003		
17	IKO, EKET	Sept, 1999	Akwa-Ibom	Unknown
18	Ubale Kerere	Aug, 2004	Ondo	Unknown
19	Ruptured Old Oil	Dec, 2008	Delta	Unknown

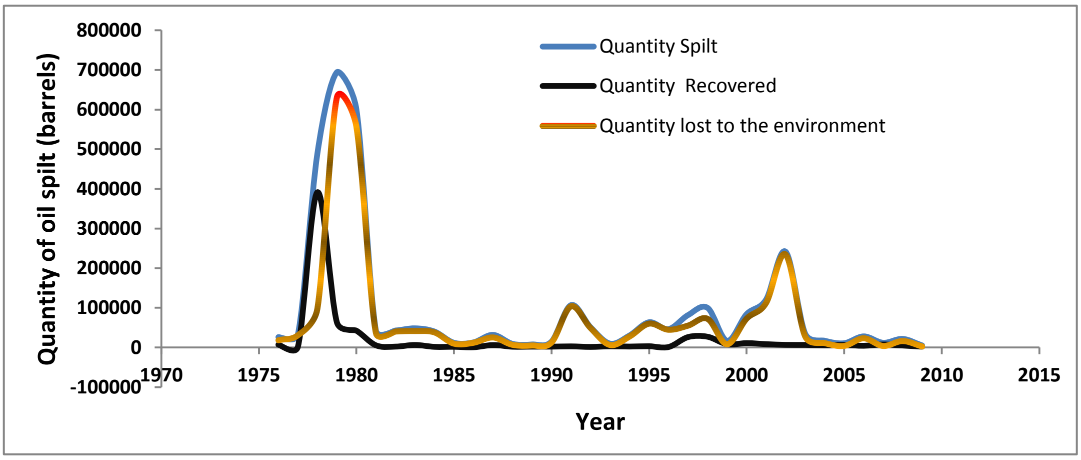


Figure 2.19. Quantity of oil spilt per year in the Niger Delta (Data source: NNPC reports).

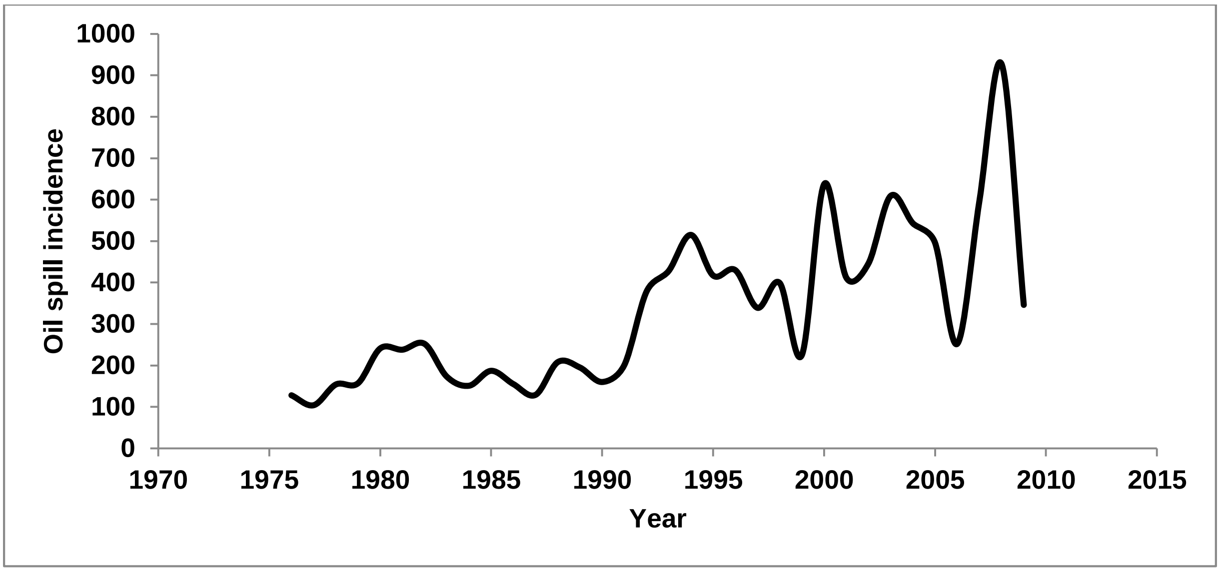


Figure 2.20. Oil spill incidence and trend per year in the Niger Delta, 1976 to 2008 (Data source: NNPC report).

The Niger Delta experiences recurrent occurrence of severe oil spills, which are not internationally published, like that of spill in the Gulf of Mexico, USA in 2010 (The Observer, 2010). The most hazardous recent occurrence was that of May 2010 and January 2012 in Ibeno of Akwa Ibom state, and Koluama communities in the Southern Ijaw Local Government Area respectively. In Ibeno of Akwa Ibom state alone, more than a million gallons of oil was spilt within seven days (The Observer, 2010). This alarming event was as a result of a ruptured pipeline belonging to Exxon-Mobil. Simultaneously during the period of the Ibeno spill, thousands of barrels of oil were spilt by Shell Trans Niger Pipelines. In the same month, two other spills were also reported in Bayelsa, with a large of slick found floating on Lake Adibawa; and another spill in Ogoni Land (The Observer, 2010). In January 16 2012, there were serious operational failures which led to oil spill and the outbreak of a fire in Koluama communities in Southern Ijaw Local Government Area of Bayelsa State. Chevron has been operating in this oil field since 1953, ever since the inception of the oil operations in the area, oil spill and pollution from oil production have reoccurred (Okon 2012). The recent spill has caused much damage to the marine ecosystem (Figure 2.24).

The flaring of gas has been on-going problem in the Niger Delta and the trend has been increasing since 1970 (Figure 2.21), until recently, when there has been reduction in gas flaring by oil and gas companies operating in the region. This reduction is because government of Nigeria and oil companies have addressed the problem to a large extent by capturing the gas for liquefaction and export. Before this, Nigeria flared about 75% of the gas she produces (ERA/FOE Nigeria 2005; UNDP 2006; Amnest 2009), as a result of pollution from soot (Amnest 2009). Awosika (1995) stated that out of 125.5 million cubic meters of gas produced in the Niger Delta region between 1970 and 1986, about 102.3 (over 81.7%) million cubic meters were flared, while only 2.6 million cubic meters were used as fuel by oil producing companies, and about 14.6 million cubic meters were sold to other consumers.

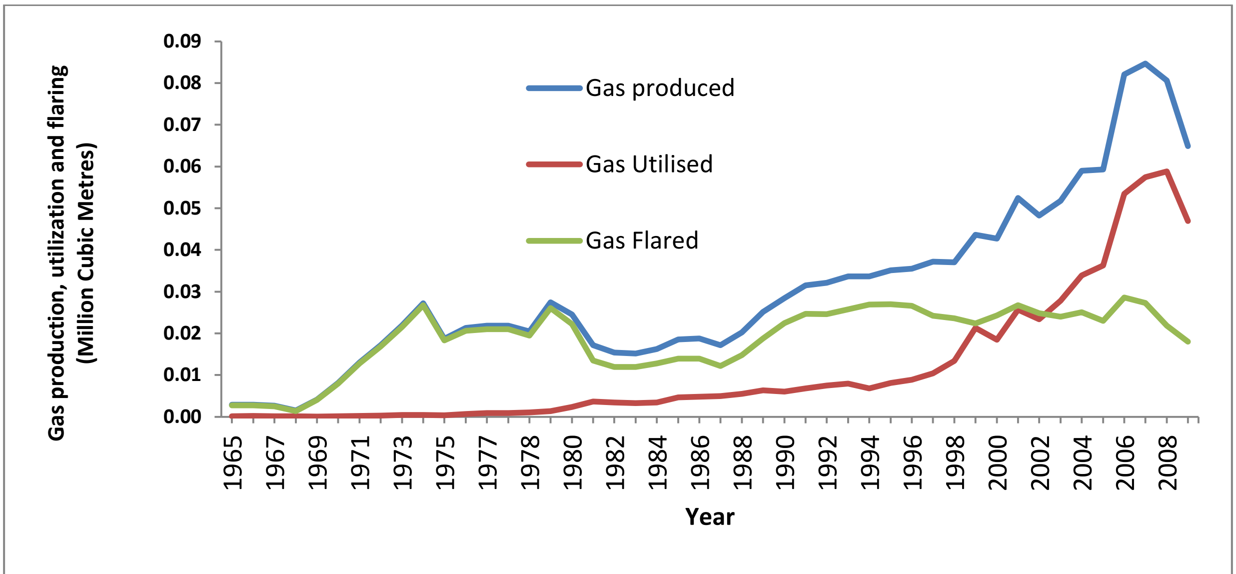


Figure 2.21. Quantity of gas flared in Nigeria from 1965 to 2009 (Data source: NNPC database).

Figure 2.22. Photo of oil spills resulting to burning of forest in the Niger Delta (Photo courtesy: Green Business Africa).

Figure 2.23. Photo of contaminated water in the Niger Delta (Source: Photo taken during the field work, 2011).

Figure 2.24. Photo of oil spill and fire outbreak in January 2012 in the Niger Delta (Photo courtesy: http://truecostofchevron.com/20120528-chevrons-worst-year-ever-nigeria.html).

Oil production can also directly lead to vegetation destruction. A study by Ebeku (2006) noted that clearing of land to lay seismic surveys and canal construction has a long-term effect, particularly on the mangrove vegetation. In West of the Delta, World Bank (1995) has reported the impacts of oil production in the Tsekelewu region. The Tsekelewu oil field provides an unusual example of how oil development can have unforeseen, but direct environmental consequences. Fagbami *et al.* (1988) reported problems associated with canal construction in oil fields and subsequent destruction of freshwater mangroves forests. Between 1980 and 1988, several canals were dredged around Tsekelewu by oil companies to link their oil fields with Atlantic Ocean for easy transportation of crude oil (World Bank 2008). Fagbami *et al.* (1988) and the World Bank (2008) noted that this exposed the fresh water vegetation to high salt water concentration from Atlantic Ocean via this canal network leading to the destruction of freshwater mangrove forest. Studies have estimated that it takes over thirty (30) years for mangroves to recover after being degraded by this disturbance (Enemugwem 2009; Eregha and Irughe 2009). Furthermore, as a consequence, some rivers in the region are heavily polluted by seawater, many of which serve as the main source of water for domestic cooking (Figure 2.23). Though scientific investigation has not been conducted towards the consequences of people drinking brackish water, but hospital records have shown a high incidence of breathing difficulties and pain amongst children (Ologunorisa 2001).

2.7.4. Political Drivers of Landuse Change in the Niger Delta

Though previous studies have reported that socio-economic activities in the Delta are the major causes of landuse change in the region, it is however clear that environmental problems in the Niger Delta are also associated with political and corruption problems (Eregha and Irughe 2009). Deforestation and degradation of protected areas in the region are partly results of corruption, disorder and mismanagement (Hellermann 2007), what complicates the situation is the lack of political will (Ehwarieme and Cocodia 2011).

To combat the landuse change and other environmental problems in the Niger Delta, the Federal Government of Nigeria has set up environmental policies, laws and agencies to implement environmental legislation, but, these agencies do not function and many of these regulations and laws are unenforced. For example, the Niger Delta Development Commission (NDDC) has a mandate to find solutions to the landuse change and other social and environmental problems facing people of the Niger Delta region. Also, the Department of Petroleum Resources (DPR) and National Oil Spill Detection and Response Agency (NOSDRA), under the Ministry of Environment, was set up to oversee the operations of industries in the region and to make sure that their production is done with adequate environmental sustainability. The main aim of establishing these agencies is to monitor oil and gas activities in the Niger Delta and to suppress the environmental and ecological impacts of oil exploration and production in the region (Ndubusi and Asia 2007). A wide variety of environmental measures have been carried out also by Federal Ministry of the Environment to combat environmental problems. The Federal Ministry of the Environment has pushed an agenda that makes priority issues of landuse change, impacts of oil production, and other industrial pollution in the Niger Delta. Table 2.4 outlines the environmental legislation that can be used to protect the Delta.

Table 2.4. Legislation relating to environmental pollution and biodiversity conservation in Nigeria (Source: Ogbnigwe 1996: 16-17).

Legislation Area	Laws/Regulations	Degrees of Community Protection
Noise	Workmen Compensation Acts 1990. State Environmental Sanitation Edicts. Factories Act. FEPA and SEPA Decrees & Edict.	Not in force [sic] at all and inadequate laws.
Wildlife -Conservation	Endangered Species Act Cap 108 LFN* 1990. Natural Resources Conservation Council Act Cap. 286 LFN 1990. Forestry Law.	Not properly enforced and inadequate laws.
Pest Control	Public Health Laws. FEPA Act Cap 131 LFN 1990.	Laws are antiquated in terms of penalties, implementation and application and have been dropped in the present laws of the federation.
Fishery	See Fisheries Act Cap 404 LFN 1990.	Lack of enforcement and poor coordination and inadequate laws.
Water	Mineral Oil (Safety) Act Cap 350 LFN 1990. Mineral Resources Act Cap 226 LFN 1990. Oil in Navigable Waters Act Cap 339 LFN 1990. Petroleum Act Cap 350 LFN 1990. River Basins Development Authorities. (RBDA) Act Cap 396 LFN 1990. FEPA Act Cap 131 LFN 1990.	Inadequate, antiquated and finally omitted in the Federal Laws but still effective in the Delta States Colonial and not in use [sic] Not adequately in force [sic] and do not favour the communities.
Land	Land Use Act Cap 202 LFN 1990. Handful Wastes Act Cap 16 SLFN 1990. Natural Resources Conservation Council Act Cap 131 LFN 1990. FEPA Act Cap 131 LFN 1990.	Favour and protect interest of government and not communities All these laws favour and protect government not the communities. Not properly enforced.
Industry	FEPA Act Cap 131 LFN 1990. Harmful Wastes Act Cap 165 LFN 1990. Environmental Impact Assessment (EIA) Decree 1992, No.86. SEPA Edicts.	Not properly enforced. FEPA not equipped to enforce the regulation. Provisions to witch hunt communities and rob them of right to compensation i.e. sabotage.
Oil and Hazardous Substance	Petroleum Act Cap 350 LFN 1990. Petroleum (Drilling and Production) Regulations 1969. Associated Gas Re-Injection Act Cap 20 LFN 1990.	Did not adopt environmental consideration and so cannot protect communities interest Not effective
Sanitation	Public Health Law. Environmental Sanitation Edicts. FEPA Act Cap 131 LFN 1990.	Antiquated. Not properly in force [sic]. Not properly in force [sic]; waste dispersal and not waste disposal.
Air	FEPA Decree No.56 of 1988.	

LFN stands for the Laws of the Federation of Nigeria.

However, many of these laws are not properly enforced while many of environmental organisations are incapacitated, due to lack of political will and insecurity in the Delta. The major piece of environmental legislation is that of Federal Environmental Protection Agency (FEPA) Act of 1988 (Frynas 2000), which gives broad legal power to FEPA to enforce environmental control in deforestation, landuse change, oil-related and other industrial activities. It is stated in section 20 of the Act that discharge "*of any hazardous substance into the air or upon the land and the waters of Nigeria"* is prohibited. According to Frynas (2000) and Ebeku (2006), such environmental pollution and degradation of Nigerian ecosystem is counted as a crime and monetary penalties are applied to the polluters. However, because of corruption and lack of political will, this law is unenforced (Ugoh and Ukpere 2010).

Corruption operates at a number of levels, which includes: looting of oil revenues by well-placed military and political representatives, kickbacks for various environmental conservation policies and contracting work, use of oil mortgages to acquire loans from international financial institutions with promises to spend this on environmental remediation in the Niger Delta, and then using the money for personal gains.

Recent studies (Ugoh and Ukpere 2012; Omorovie 2012) have examined the failure of the environmental policies and legislations on the Niger Delta and its consequences on physical environmental health, values and philosophy of the people living in the Delta. The major findings of these studies are that corruption and unenforced environmental laws are the major challenges in the Delta. These problems have been recognised also internationally for example, a UNEP EA report recommended setting up appropriate authorities for implementation of conservation of biodiversity and other forest resources in the Niger Delta (UNEP EA 2011). However, the report recognised that for this to be done, the legal framework on environmental protection, conservation and management needs to be effectively enforced, especially existing laws in relation to environmental pollution, deforestation and biodiversity conservation in the Niger Delta (Ugoh and Ukpere 2012).

Another major challenge in the Niger Delta is insecurity. The Niger Delta is well-known for insecurity as a result of regular violence and lawlessness by indigenous people. The region has witnessed numerous conflicts in the past few decades, due to the government's empty promises toward reduction of environmental degradation resulting from oil and gas production (Babatunde 2010), thus makingconflicts and kidnappings to be frequent. Communal and political unrest persisted throughout the 1990s till 2007, despite the election of a democratic government (HRW 2002; Ugoh 2010). However, the introduction of an amnesty programme in 2008 has led to a significant decrease in the incidence of conflict in the region, though no one is sure if this will lead to a total eradication of the violence (Watts, 2005; 2008; World Bank, 2008).

2.8. Landuse Dynamics in the Niger Delta

A significant amount of literature documents the character of landuse change in Nigerian Delta, but in order to use land optimally, it is not only necessary to have the information on existing landuse, but also to have the capability to monitor the dynamics of landuse resulting from complex drivers. Agriculture is still a major component of the landuse in the Niger Delta (Aaron 2006), and the main crops which are grown in region are tuber root crops such as cassava and yams; and tree crops such as oil palm and rubber. Major agricultural systems include plantation cultivation; shifting cultivation which involves rotational bush fallow; agro-forestry and livestock production (Alagoa *et al.* 1988). Plantation cultivation involves cultivation of patches of land continuously, and involves perennial tree crops like the oil palm (*Elaeis guineensis*) and rubber (*Hevea brasiliensis*) around or near houses in a rural setting. Shifting cultivation is characterised by rotational bush fallow, in which a farmer usually owns several plots of land within which he cultivates sequentially on a rotational basis.

The agroforestry system is also common, in which people engage in the practice of integrating trees into farmland in order to maintain soil fertility, thereby increasing the farm productivity. Oil palms (*Elaeis guineensis*) and rubbers (*Hevea brasiliensis*) are the most common tree crops because of their economic importance (NDCC 2001; Jike 2004). For example, oil palm is the main source of vegetable oil for local cooking, not only in the Niger Delta region but all over West Africa. Produce from rubber trees are processed into rubber sheets or lumps. Initially, most of rubber was exported, but now, they are mainly used locally in shoe, tyre and mattress industries.

Variation in settlement patterns constitutes a major landuse dynamic in the region. To understand the settlement pattern, according to Nzewunwa (1988), the relationship between resources potential and settlements around them is important. There are about 13,329 settlements in the Niger Delta (NDDC 2001). The predominant settlement type is scattered rural hamlets. Rural settlements (less than 5,000 inhabitants) constitute about 94% of the total number of settlements. Many rural settlements lack essential amenities, such as medical facilities; good water; power supply and good transportation systems. There are also several towns and cities which are usually separated from clusters of rural settlements by rotational farmland, oil palm or rubber plantations. The main urban settlements in this category include Port Harcourt, Warri, Akure, Asaba, Benin, Calabar, Uyo, Umuahia, Aba, Owerri and Yenagoa, many of which are capitals of states. Poor ground drainage in a low relief region may be the primary factor responsible for the low number of urban settlements in some regions, such as the swamp forest. The urban settlements are found in the parts of the Delta that have better drainage and accessibility conditions. The location and pattern of rural settlements in the region are influenced by access via roads, the availability of dry land for agricultural activities, water bodies for fishing and the nature of the terrain.

It is clear from the above studies and other recent research on the Niger Delta (e.g. Were 2009; Morakinyo and Tooze 2007; Ibaba 2010, Bown *et al* 2011) that there are contradictory figures about the rate of deforestation and drivers of landuse change in the Delta. For example in Bayelsa State, Ibaba (2010) reported that the state loses about 3% of the forest annually while Onojeghuo and Blackburn (2011) reported 0.75% annual rate of deforestation for the entire Niger Delta. On the other hand, an earlier study by Were (2009) estimated that about 50% of forest in the Niger Delta has been lost as a result of deforestation and indiscriminate logging by local inhabitants, though he did not put a time frame on this estimate. Recent studies by Morakinyo and Tooze (2007) and Bown *et al* (2011) have reported that over 56% of forests in Nigeria have been lost with about 3.5% rate of deforestation annually. Morakinyo and Tooze (2007) explained further that only 10% forest remains in the country, half of which is located in the Niger Delta. These values vary and there are sometimes large discrepancies. However, they all agreed a high rate of deforestation compared with 0.28% found in Cameron and Vietnam by Mertens and Lambin (2000), and Meyfroidt and Lambin (2008).

2.9. A Conceptual Model of the Drivers of Landuse Change in the Niger Delta

From abundant and sometimes contradictory conceptions of environmental change examined in the literature reviewed above, this section introduces the conceptual model that underlies this study. Broadly speaking, three major concepts explain the drivers of landuse change in the literature: proximate, underlying and other drivers. Proximate drivers of landuse can be interpreted as the direct factors which drive environmental change, and subsequently have direct impacts on the rate of landuse change in a region (Lambin *et al.*, 2001). Examples of proximate factors are agricultural activities, wood extraction and infrastructural expansion. On the other hand, underlying drivers are fundamental forces that strengthen more obvious proximate causes. Underlying factors include such drivers as complex socioeconomic, demographic, cultural, technological and political influences that create initial conditions in the human-environmental relationship. Other drivers of landuse include predisposing environmental factors (e.g. soil types and processes), social trigger events (e.g. social disorder and war), and biophysical drivers (e.g. ecological succession, weather and climate variations), which enhance rapid change in the landuse in some areas, but not others.

Geist and Lambin (2001) developed a conceptual model that explains the causes outlined above (Figure 2.25). The model was based on the subnational case study evidences of deforestation in the tropical region, with the main research question focusing on “what drives tropical deforestation?” Proximate drivers of landuse change, according to this model include immediate and local factors that have direct impacts on landuse pattern (Geist and Lambin 2002). The most important proximate factors of landuse change in the tropical region are agricultural expansion, wood extraction and infrastructure extension (Figure 2.25).

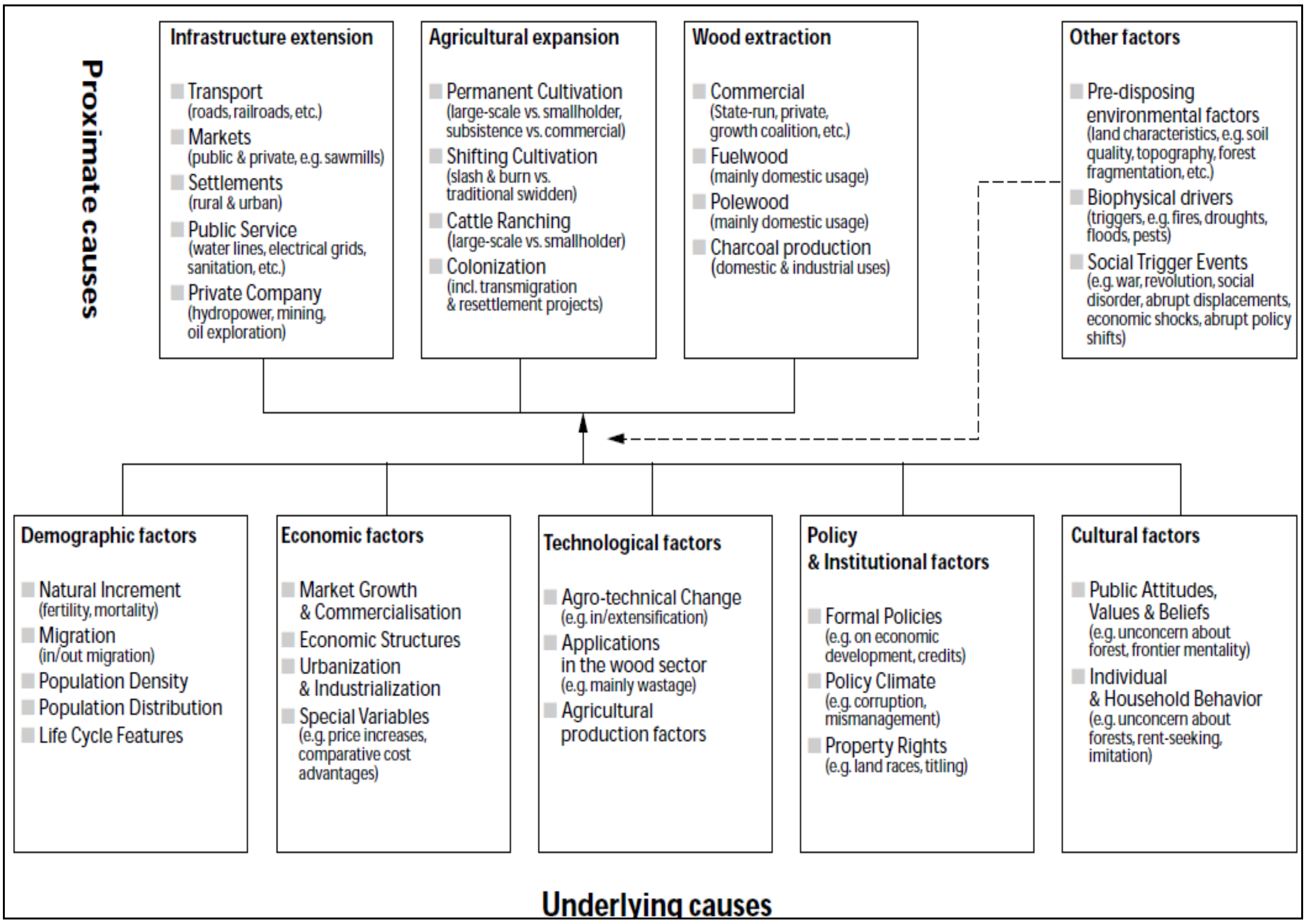


Figure 2.25. Drivers of deforestation in the tropical region (Source: Geist and Lambin 2001).

According to Geist and Lambin (2001), the underlying drivers may include indirect impacts of national demographic and socioeconomic factors (e.g. national economic development) or the direct impacts at the local level (e.g. local population density). The categories of "other factors" in the model compose of biophysical drivers, pre-disposing environmental factors and social trigger events (Figure 2.25). However, the conceptual model considers the complexity of many drivers of the landuse, ranging from demographic; societal; economic to biophysical drivers; political factors and influences of global and local economy. The model aids better understanding of three major categories of drivers of landuse change discussed above, and this has been increasingly recognized as the key research imperatives in the tropics (Lambin *et al* 2003). The model also allows identification of the causality behind change in landuse at the regional and local levels and helps comparative analysis of the major process of deforestation, for future policy intervention (Figure 2.25).

Some of the drivers identified by this model (Figure 2.25) are yet to be identified in the Niger Delta. Table 2.5 illustrates the drivers of deforestation as observed in the Niger Delta and drivers found in other parts of the world, but not yet identified in the Niger Delta. In the Niger Delta, the literature review findings show that much emphasis has been on the impacts of oil production, population growth, communal and commercial timber logging, firewood collection, urbanization and unenforced environmental protection laws (Godstime *et al*. 2007; Morakinyo and Tooze 2007; Ibaba 2010; Ehwarieme and Cocodia 2011). For example some studies have argued that lying of seismic lines and dredging are two oil production activities that degrade forest in the Niger Delta. They open the forest reserves for illegal timber loggers through tracts cut into previously inaccessible pristine forest areas. Furthermore, some of the oil pipelines in the Delta pass through protected areas and many of these pipes are old causing oil leakage, leading to death of tree species that are not oil tolerant (Babatunde 2010; Omorovie 2012; Iwegbue *et.al.* 2012). Population growth in the Niger Delta is considered a major contributor to deforestation in two major ways. Firstly, it increases the total national population and also increases the demand for food production from subsistence farming and timber for construction of buildings. Thus, expansion of farmland into forested area and timber logging enhances rapid deforestation (Bamgbose 2009; Ibaba 2010).

Comparing the model (Figure 2.25) with Table 2.5, the key proximate drivers of deforestation found in other parts of the world (Figure 2.25) but not yet identified in the Niger Delta include cattle ranching, colonization and transmigration or resettlement, charcoal production, and infrastructures such as road network (Table 2.5). For example, impacts of small and large scale colonization and transmigration were identified as one of the driving forces of deforestation in cases of Borneo and Malay Peninsula (Geist and Lambin 2001). Furthermore in the Amazon, cattle ranching converts forest to pasture. Nevertheless, this variable is not evident in the Niger Delta because there is no large scale cattle ranching, but this might be of greater impacts in the northern part of the country where people practice pastoral agriculture. What is evident from literature is forest removal due to the establishment of agro-industrial plantations which occurs in many parts of the Delta (Table 2.5).

Table 2.5. The drivers of deforestation but not yet identified in the Niger Delta.

Drivers of deforestation as observed in the Niger Delta	Drivers of deforestation found in other parts of the world but not yet identified in the Niger Delta
Proximate drivers : • Wood extraction such as commercial and fuel wood collection, firewood and pole wood extraction. • Timber logging and sawmilling. • Construction of canals. • Agricultural expansion both subsistence and plantation agriculture. • Impacts of oil industries.	• Infrastructure expansion such as road networks. • Charcoal production. • Cattle ranching. • Colonization and transmigration or resettlement.
Underlying Driver: • Ineffective forest management. • Demographic factors such as rural-urban migration and natural increase in population. • Lack of political will. • Corruption and lawlessness. • Cultural factors such as unconcerned attitude of people living in the Delta. • Urbanization and industrialisation.	• Agro-technical change. • Increased price of land and comparative cost advantage. • Market growth and commercialisation. • Life cycle features.
Other Factors: • Pre-deposing environmental factors such as topographical nature and land characteristics. • Biophysical factors such as nature of the soil and drainage system. • Social trigger events such as social unrest and policy shift.	• Prevailing ecological system. • Irrigation. • Drought and flooding.

The impact of market growth, commercialisation and other special variables such as increase in the price of land and comparative cost advantage have not been identified so far in the Niger Delta. Although, global and local market growth often involved in deforestation processes in other part of the world (Lambin *et al* 2001; Geist and Lambin 2002), these have not been seen play a relevant role in the Niger Delta, because of lack of adequate data on the local economy. Studies have reported that rural population were also attracted into the market economy by the increased commercialisation of crops, contrasting of farming in other parts of the world (Vanwambeke *et al.*, 2007), yet such a process has not been recognised in the Delta as there is little commercial cropping. Life-cycle is a demographic factor identified in the model (Figure 2.25) that explains households' strategic responses to both socioeconomic opportunities (e.g. market growth, commercialisation, increased price of land) and constraints (e.g. economic crisis conditions and comparative cost advantage that arise from the increase in the price of land), whichhas not yet been identified in the Niger Delta, perhaps because of a lack of socioeconomic research (Table 2.5). Studies have shown that these factors may sometimes trigger agro-technical change, even though agro-technical change as a driver of deforestation is complex, and does not provide an "easy-to-generalize pattern" (Lambin *et al.* 2003; Vanwambeke *et al*. 2007).

Other factors that are not yet identified in the Delta include influences of irrigation, climate extreme events such as drought and flooding, charcoal production, and influence of infrastructure such as road networks (Table 2.5). The biophysical drivers of landuse in the Niger Delta have received little attention in the literature. The impact of irrigation and extreme climate events such as drought and flooding on landuse change are complex issues.
For example, Geist and Lambin (2002) have noted that irrigation and climate extremes might have little influence on the expansion of crop landuse, but more for pastoral agriculture in the tropics, especially smallholder cattle ranching. Therefore, it was argued that combination of other factors, such as ecological quality and cattle ranching appears to drive exceptionally high deforestation in the region. Charcoal production and irrigation are not common in the Niger Delta due to the high rainfall. The influence of infrastructure such as road networks in the Delta are little studied. In other parts of the world, studies have discovered the significant impacts of accessibility created by road network on the rate of deforestation. Principal among such studies are those by Lambin *et al* (2001); Geist and Lambin (2001); Lambin *et al* (2003); Estes *et al* (2012); Patarasuk and Binford (2012). For example, Geist and Lambin (2001) and Lambin *et al* (2003) have identified accessibility through road extension as the major proximate driver of tropical deforestation, especially in Indonesia, Malaysia, and Latin America. A recent study by Patarasuk and Binford (2012) also noted that the road network development is an important factor of deforestation in the Lop Buri province of Thailand. Given the expanding road network in the Delta, and a lack of study on its role in deforestation, but its importance in other areas, one of the objectives of the present study is to carry out an empirical analysis of the impacts of road network development, together with other factors, on deforestation in the Niger Delta.

The major reason for adopting and testing the conceptual model outlined above in the present study of drivers of landuse change in the Niger Delta is to challenge single-factor explanations of many of the previous studies. Understanding of the drivers of environmental change has been the contentious question in the Niger Delta, thus application of this model highlights the importance of considering the nonlinear effects of the combination of many drivers of landuse change in the Delta.

2.10. Summary of the Chapter

This chapter reviews natural resources endowment and environmental problems in the Niger Delta. What is evident from the literature reviewed so far is that the region is rich with natural endowments such as mineral resources, forests, fauna and other biodiversity, but these resources have been subjected to severe degradation. Several environmental problems have been identified by previous studied including: land degradation due to commercial and communal logging, rapid population growth and urban expansion, coastal erosion and flooding and environmental pollution by oil and gas industries. These problems are compounded by numerous conflicts, violence, kidnapping and insecurity in the region. The comceptual model developed in this chapter shows that the drivers of environmental change in the Delta are many and complex. What complicates the situation is the lack of accurate data which is militating against appropriate decision making and planning in respect of environmental problem in the region. Consequently, there have been difficulties in understanding the rate of environmental dynamics in the region. Thus, remote sensing and satellite Imagery techniques are promising methods that can help in assessing the scale and extent of loss of land and this is the focus of this research.

CHAPTER THREE
METHODS FOR MONITORING ENVIRONMENTAL CHANGE: A LITERATURE CRITIQUE

3.1. Introduction

Different datasets have been used in the literature to assess landuse change. Such data could be broadly categorised into two main groups: remote sensing and non-remote sensing data. Remote sensing data are those data collected through various devices without human contact with the field, while non-remote sensing data are those acquired by other means. This chapter aims at reviewing both remote sensing and non-remote sensing data and methods used in landuse change assessment. The chapter is divided into three major sub-headings: Different non-remote sensing methods used in landuse change assessment, their merits and limitations; uses of Earth observation satellite in landuse change assessments; and the need for linking non-remote sensing and remote sensing data in landuse change study, in relation to the problems that have been explained (chapter 2) as predominant in the Niger Delta.

3.2. Non-Remote Sensing Approaches: Application of Social Research Methods for Better Understanding Environmental and Societal Changes

Several non-remote sensing approaches have been used in the literature to collect primary data for landuse change assessment. Data in this category include field observation; social and economic survey data; as well as reports relating to landuse change in a given location. Many of these data are also used to assist in remote sensing analysis of landuse change for identification and interpretation of landuse features from remote sensing, and how they change over time (Campbell 2002). Detailed discussions of various non-remote sensing data and methods for landuse change examination could form a research project on its own, but this study addresses the most common methods used in the literature. Therefore, this section reviews the merits and limitations of commonly used social survey data and methods, as presented in Table 3.1. Such methods include: questionnaires; interview techniques; focus group discussions; ethnography and participant observation; and e-data collection in terms of using the internet as the object and method of data collection (Table 3.1).

Table 3.1. Social data collection: their merits and limitations.

Methods	Uses	Limitations	Data produced
Questionnaires	Quantitative	-Cannot build trust. - Cannot ask sensitive questions.	-Single clearing YES/NO questions.--- -Can ask a lot of people, thus can get a lot of data. - Can apply statistical analysis.
Interview	Qualitative	-Can build trust. -Can ask sensitive questions. -Time consuming. -Can only get limited data.	-“Rich” in cultural data -Trying to see into respondents’ world and understanding how they think. -Report as narrative.
Group interview	Qualitative	-More difficult to build trust with a group -Some participants may be intimidated by others. -It is not “private”.	-Mostly qualitative. -May be a major opinion.
Focus group	Qualitative	-Some participants may be intimidated by others. -Some may not engage with you in discussion.	-Interaction between participants may raise issue that the researcher is not asking about, and had no thought of.
Ethnography and participant observation	Qualitative	-Gaining access to some communities may be very difficult. -Security might be a problem in a region with frequent crisis.	-The researcher becomes part of the society for a long time. -Data collected are huge and qualitative in nature, thus statistical analysis of such may be difficult.
E-data collection	May be qualitative or quantitative	-Real-time data collection is possible. -Cannot be used in developing countries with little or no access to internet.	-large amount of data can be collected. -statistical analysis of data is possible.

Questionnaires are commonly used as a tool for collecting social data relating to landuse change, especially in human geography. Questionnaire survey is a research method for generating and exploring people's perceptions, experiences and spatial interactions by administering a standardised set of questions to a sample of individuals. In geographical studies, questionnaire surveys have been used to address a wide range of geospatial issues. Parfitt (2005) detailed the advantages and limitations of the method, together with an extensive discussion of issues relating to design and conducting of questionnaires. A major limitation of the questionnaire approach, according to Parfitt (2005) and Marshall and Rossman (2011) is that it does not allow the respondents to express their feelings, knowledge and experiences about the subject matter of the research, which might be due to the fact that the respondents are usually restricted to the questions in the questionnaires.

As a result of this limitation of questionnaires, many researchers prefer in-depth interviews. Studies have shown that such interviews provide a better tool for collecting more detailed social data on causes and effects of landuse change than generally possible in questionnaires application (Bryman 2004; Valentine 2005; Marshall and Rossman 2011). Interview can also ask supplementary questions and probe to investigate research problem in detail. On the other hand, Valentine (2005) has noted that the major limitation of one-to-one interview is that researcher could only talk to one person at a time, thus in-depth interviews will generate fewer respondents than a questionnaire-based approach. It should be expected that analysis of data collected from interviewers should therefore be quicker and more cost effective than that from questionnaire-based approach. However, speed of analysis and cost effectiveness depends on the nature of research and quantity of the data generated. The resultant data are then reported as a narrative, sometime including direct quotes from the respondents.

In the literature, several studies used ethnography and participant observation not only because they collect more information, but also because they overcome some of the limitations of questionnaire. Ethnography and participant observation approaches are methods which entail involvement of the researcher in the social life of the people they study (Bryman 2004). Ethnography and participant observation involve a long observation whereby full participation of researcher in the peoples life is required, in order to obtain social data (Marshall and Rossman 2011). Studies have established the merit of ethnography as it encourages long-time interpersonal interaction with the people, so as to obtain very detailed information, and also aids in better understanding of the study area (Valentine 2005; Marshall and Rossman 2011). The main limitation of ethnography and participant observation is that they cannot be used in a region with regular unrest, such as the Niger Delta of Nigeria.

A focus group is a group of people who meet in an informal setting to talk about a particular topic that has been set by the researcher (Longhurst 2005). The idea behind the focus group discussion is that people who were known to have had certain experiences on the research topic usually participate. Using this method, the researcher facilitates the discussion, but do not lead. Bryman (2004) and Frankfort-Nachmias and Nachmias (2008) have extensively reported the merits and limitation of focus group methods over questionnaire survey and one-to-one interview. Bryman (2004) reported that more information can be obtained from a group of people than a one-on-one session or an in-depth interview. This might be because people who were known to have had certain experiences on the research topic are interviewed, thus there is a merit of obtaining more information from those people. Similarly in focus group, broad topics are raised to allow the participants to discuss. In this way, it is hopeful that issues will arise that the researcher has not thought of, and would not have asked about in questionnaire and interview. Nevertheless, Conradson (2005) noted that there is potential problem of generating controversial opinion from group of people, and this makes the analysis of data generated from focus group discussion difficult. A focus group may gather more opinions, but may lose validity, because it is harder to build trust with a group, and the group may not trust each other. Despite this limitation, what is obvious from above is that focus group might be used to obtain more information about drivers of landuse change and assess social and economic implications of such changes, which is not possible to obtain through remote sensing data (Gautam and Chennaiah 1985; Miller *et al*.1998).

In recent years, electronic means of data collection have been used by researcher to collect social data. This method involves the use of World Wide Websites, social media and online social survey to collect social data (Evans *et al.* 2001; Sweet 2001). Using these tools, real-time data could be collected. It is possible to conduct online personal interview using Skype and other teleconferencing methods;, design and conduct online questionnaires using survey monkey and other online questionnaires platforms; and online focus group discussion using social media. However, the major limitation of this approach is that it is not effective in developing countries such as Nigeria, where there are irregular power supply and internet facilities are not generally available for people.

Despite the benefits of the social survey approach in landuse assessment, studies have shown that such data cannot be used for rigorous spatiotemporal analysis (Defries and Belward 2000; Boakye *et al*. 2008). This is because these data may not be available continually over some period of time and space. Availability of these data influences the choice of scale or aggregation of the landuse. A study by Yang and Liu (2005) has noted that application of non-remote sensing data in landuse change analysis cannot provide adequate information per time slice and it is not cost effective. Thus, monitoring landuse change using non-remote sensing dataset is not only time and labour intensive, but is also difficult to monitor spatiotemporal landuse change (Dixon *et al*. 1994). Similarly, the usefulness and interpretation of social data and methods depend on the interpreter's experiences and knowledge in applying the data (Yang and Liu 2005).

It is clear from above that application of non-remote sensing data in landuse change assessment and integration of such data with remote sensing analysis depends on the nature of research, the characteristics of study area and compatibility of data with the remote sensing data. Participant observation cannot be used in a region with regular unrest and similarly, electronic means of data collection cannot be employed in the Niger Delta where there is frequent kidnapping and power failure. In addition, some social data cannot be used for rigorous spatiotemporal analysis, if such data does not have adequate spatial and temporal characteristics. Consequently, this present study uses a mixed method approach: questionnaire, interview and focus group discussion to collect social data. Mixed methods were used in this research because the strength of one method complements the weakness of the other, and also gives confidence about the results of findings from remote sensing, and thus enhances good research quality. The social data collected will then be used to validate the findings of the remote sensing data. In other words, this data is used to enhance the interpretability, meaningfulness and validity of results from remote sensing. The details of the research methodology are presented in the next chapter.

3.3. Remote Sensing Approaches

Based on the limitations of non-remote sensing data discussed in section 3.2 above, many studies have used remotely sensed data to assess landuse change (Lambin *et al.* 2003; Kreuter *et al.* 2011; Estes *et al.* 2012). Remote sensing data are used in landuse change assessment because it has the advantage of providing a relatively accurate means of measuring the extent and pattern of changes over time (Yang and Liu 2005, Ouyang *et al.* 2010). This section discusses the range of remote sensing data sources and methods available for landuse change detection analysis.

3.3.1 Remote Sensing Dataset for Land Use Change Assessment

Selection of appropriate remote sensing dataset and method(s) for a landuse change detection research project is essential. Data selection is important because any landuse change detection depends on multi-temporal datasets in order to quantitatively examine both spatiotemporal effects and interactions between human and natural phenomena, although there are many datasets available (Seto *et al*. 2002). Several different remote sensing datasets have been used in previous studies for landuse change detection analysis, choice of remote sensing data depends not only on the scale of the project, but also on the availability of data and funds to acquire such data (Mertens and Lambin 2000).

Generally, remote sensing data that have been used in landuse studies could be grouped into three major classes, based on the remote-sensing platforms used. Such categories of data, according to Aplin (2005), include those that are collected using ground-based platform like hand-held instruments; those that are collected using airborne platforms like aeroplanes and helicopters and those data collected using satellite platforms and other spacecraft such as space shuttle. The most commonly used satellite remote sensing data in landuse studies include Landsat TM and ETM+, SPOT, MODIS, NOAA–AVHRR, IKONOS and QuickBird. Table 3.2 outlines the characteristics of these sensors as related to landuse studies. Similarly, MODIS and NOAA–AVHRR are suitable for landuse mapping at a global scale (Lu *et al,* 2004), SPOT, Landsat TM and ETM+ capable for regional scale (Hansen and Loveland 2012; Kovalskyy and Roy 2013), while IKONOS and QuickBird can be used for landuse change mapping at a local scale (Avitabile *et al*. 2012).

No matter the category of the data, a general review of the literature shows that a number of factors determine the remote sensing data to be used in landuse change analysis (Lambin *et al*. 2001; Shi *et al*. 2002; Hansen and Loveland 2012). Aplin (2005) listed major data characteristics that influence how the remote sensing data might be effectively used in landuse change assessment, these are: spatial, spectral, radiometric and temporal resolution of the data and the data format.

The utility of remote sensing data in landuse change investigation is to a large extent controlled by their spatial resolution. The central observation in satellite data is the pixel and the size of pixel determines precisely what landuse feature might be seen on an image (Avitabile *et al.* 2012). In Table 3.2, the spatial resolution of remote sensing data were defined, based on ground sampling distance (GSD), in such that pixels with GSD > 30m is considered to be low or coarse resolution, between 2.0 and 30m are medium resolution, between 0.5 and 2.0m are high, while < 0.5m GSD are considered to be very high. For example, the spatial resolution of Landsat ETM is 30m while data from the IKONOS is 1m. The spatial resolution of remote sensing data determines the scale of use, and in what ways the data might be used in landuse change detection studies. Consequently, Landsat and SPOT are recommended for regional landuse projects, while MODIS and AVHRR are suitable for global landuse studies because of their low spatial resolutions and wide area coverage (Salami *et al* 1999; Lu *et al*. 2004).

Spectral resolution is another feature of remote sensing data which determines the selection of data to be used in any landuse change research. Spectral resolution denotes the sensitivity of different sensors to wavelengths of electromagnetic radiation. It represents also the part(s) of the electromagnetic spectrum used to generate an image (Aplin 2005). Remote sensing data used in landuse and other environmental studies can be panchromatic, multispectral or hyper-spectral, depending on the number of spectral wavebands used to acquire the image. Panchromatic data, such as aerial photography, are usually displayed in black and white, while multispectral data (e.g. Landsat-7) has more detailed information (Avitabile *et al.* 2012).

Table 3.2. The characteristics of remote sensing data as related to landuse change studies

Sensor	Application	Spatial Resolution	Swath Width	Temporal Coverage
Landsat TM	Regional scale landuse change studies.	30 m, (120 m - thermal). Medium to coarse spatial resolution.	183 km x 172 km.	16 days
Landsat ETM+	Regional scale landuse change studies.	30 m (60 m - thermal, 15 m pan).	183 km x 170 km.	16 days
SPOT	Regional scale landuse change studies	20 - 2.5 m	Each scene covers 60 x 60 km for HRV/HRVIR/HRG and 1000 x 1000 km (or 2000 x 2000 km) for VGT.	26 days nadir, 4-5 days revisit
MODIS	Global or national scale landuse change studies.	250–1000 m. Low spatial resolution	2330 Km	1-2 days
NOAA–AVHRR	Global or national scale landuse change studies.	1-km. Low spatial resolution	2400 x 6400 km	1 day
IKONOS	Local scale landuse change studies.	1- 4 m. High spatial resolution	11 x 11 km	3–5 days
QuickBird	Local scale landuse change studies.	2.4–0.6 m. High spatial resolution	16.5 x 16.5 km.	1–3.5 days

However, some remote sensing devices concurrently generate both panchromatic and multispectral images: Hyper-spectral data, such as Eo-1 satellite's Hyperion sensor, involves those data that were collected from hundreds of very fine wavebands. There is evidence in the literature that data from the Hyperion sensor might be useful for better identification of features in landuse analysis. This is because hyperspectral images generate relatively high information contents compared to other sensors (Liverman *et al.* 1998; DeFries and Belward 2000; Akgn *et al.* 2004).

Radiometric resolution of remotely sensed data determines the level of detail that could be derived from the data for landuse change mapping. The radiometric characteristics denote the quantity of distinctive brightness levels in the data. For example, a coarse radiometry resolution image might record a scene, using only a few brightness levels or a few bits while fine radiometric resolution would record the same scene using many levels of brightness. The high radiometric resolution of IKONOS, for instance, enables some landuse features in shadow to be recovered (Di *et al.* 2004, Soudani *et al.* 2006), thus making severalstudies to show many benefits of performing radiometric corrections in landuse assessment. The majority of these studies have argued that radiometric correction is required when a given landuse characterization is to be extrapolated beyond a single image. Factors such as ground and atmospheric conditions might also contribute to the variations in radiometric responses of remote sensing data. Removing these sources of data variation can improve the accuracy of landuse and their changes over time.

Temporal resolution characterizes the occurrence of revisits by a remote sensing platform. Generally, the major advantage of satellite data over other forms of data for landuse change detection studies is that it can acquire multi-temporal images over large areas. Using satellite data, it is possible to examine both spatial and temporal change in an environment. For example, using such data as Landsat ETM with 16 days temporal resolution and if more detailed temporal analysis is needed, such data as IKONOS with 4 days temporal resolution might be used.

Despite the differences in the scale, a major factor that determines the selection of remote sensing data to be used in landuse change assessment is the cost of image. Thus, when choosing imagery to be used in landuse change detection, one of the major factors considered by the researcher is the cost of imagery. The majority of high resolution images are expensive. For example, though SPOT, IKONOS and QuickBird have very high spatial resolutions, which might be used for fine-detailed landuse classifications, many research projects with little or no fund might prefer to use freely available data such as Landsat.

The key findings from several literatures reviewed are that, besides the fact that Landsat is freely available to researchers, it has also brought valuable potentials to landuse change studies. This PhD study will therefore use Landsat dataset to examine landuse change in the Niger Delta. Since the present study involves examination of landuse change over a long period of time, nearly thirty years, Landsat data is for that reason valuable for this study, to provide frequent and timely coverage of data. This is because Landsat has a long-term historical record of data for the entire globe, and it has been valued by scientists and researchers as the paradigm of land observation. It has provided one of the longest satellite datasets of the earth from space. Landsat Thematic Mapper (TM) has been carried by Landsat since July 1982 while ETM+ is the next version of the TM sensor, which was launched in April 1999 (Lasanta and Vicente-Serrano 2012). Landsat TM provides a 30m spatial resolution in 7 spectral bands (Table 4.1), and records solar reflected radiation between 0.45 and 2.35μm, though band 6 has a lower spatial resolution of 120 square meters and senses thermal infrared radiation (NASA 2000). Landsat ETM+ has the same characteristics as TM, but ETM+ has an additional panchromatic spectral channel that provides higher spatial resolution at 15m. Landsat has temporal resolution of 16 days and swath width of 186km (NASA 2010; Avitabile *et*. *al* 2012). In view of the fact that Landsat has a long history of dataset, it will be useful therefore in the present study, to map long-term changes in landuse and the spatiotemporal vegetation changes in the Niger Delta of Nigeria. Furthermore, Landsat will be used in this study because of its high-quality multispectral resolution, less costly to acquire and its adequacy for regional landuse change assessment, as in the case of Niger Delta of Nigeria.

3.3.2 Remote Sensing Methods

In addition to those factors discussed above, it is evident in the literature that to achieve accurate assessment of landuse change, four methodological steps are essential: (1) image pre-processing which includes image calibration, geometric and atmospheric correction (Jensen 1996; Weber 2001; Lambin *et al*. 2003), (2) selection of appropriate image processing methods and suitable techniques to implement change detection analyses, (3) ground truthing; and (4) accuracy assessment (Singh 1989; Lambin and Ehrlich 1997; Seto *et al*. 2002; Lu *et al*. 2004; Hansen and Loveland 2012). Therefore, it is the purpose of this chapter to review remote sensing methods that have been used to assess landuse change, vegetation degradation and examine the factors in relation to the problems that have been revealed to predominate in the Niger Delta.

3.3.3 Image Pre-Processing Methods

Pre-processing refers to those operations which are being carried out to correct the distortions or standardize an image (Aplin 2005; Lu *et al.* 2005). Typical pre-processing operations include radiometric and geometric corrections. Radiometric corrections are used to adjust digital values of image in order to correct for atmospheric effects, while the main aim of performing geometric correction is for rectification of geometric distortions resulting from geometric variations between sensor and the earth (Lu *et al.* 2005). It also includes conversion of image data to real world coordinates in terms of latitude and longitude (Schowengerdt 2007; Avitabile *et al.* 2012).

Generally, there are two opinions in literature about the importance of radiometric corrections in landuse change detections analysis. Some studies have shown that preliminary corrections are essential parts of change detection analysis, because reflectance of the objects recorded by satellite sensors is generally affected by atmospheric scattering and absorption, sensor-target-illumination geometry, and sensor calibration (Lu *et al.* 2002b; Mahiny and Turner 2007). For example, Song *et al.* (2001) noted that radiation is modified by scattering and/or absorption when passing through the atmosphere from the earth's surface to the satellite sensors, therefore, images have to be pre-processed to correct for these atmospheric effects. On the other hand, some scholars have reported that radiometric normalization is not important in landuse change detections, especially when using classification methods (Carvalho *et al.* 2001; Stow and Chen 2002; Lu *et al.* 2004; Aplin 2005). For instance, Aplin (2005) argued that radiometric normalization might not be necessary in landcover classification methods, especially when spectral signal from each individual image are used for multi-temporal image analysis. The general conclusion of Song *et al.* (2001) and other studies is that the need for radiometric normalization depends not only on the information desired and research questions; remote sensing and atmospheric data available; but also on the change detection methods used to assess landuse change. The majority of recent studies agreed on the fact that radiometric normalization is necessary when applying NDVI methods to assess vegetation change (Ogunbadewa 2008; Hansen and Loveland 2012, Islam and Ahmed 2012). Furthermore, studies by Verbyla and Boles (2000), Lambin *et al.* (2001; 2003), Hansen and Loveland (2012) further established the fact that atmospheric correction is an essential element of landuse change remote sensing. This is because it reduces image differences generated as a result of atmospheric interference during image acquisition and also influences the results of environmental change detection methods, especially vegetation indices.

What is obvious from these studies is that radiometric and geometric correction are the most important parts of image pre-processing in environmental change analysis and thus accuracy of the results from landuse change detection usually depends to some extent, on the image pre-processing stage (Lambin *et al.* 2001; 2003). For example, Verbyla and Boles (2000) and Islam and Ahmed (2012) noted that if geometric corrections are not properly done, landuse change analysis may be over/under-estimated as a result of spatial error in multi-temporal images. Thus, Lambin *et al.* (2001) had earlier recommended that adequate knowledge of radiometric and geometric properties of the sensors is necessary in any landuse change detections and other environmental change analysis, using multi-temporal satellite data.

Different algorithms are found in the literatures that perform atmospheric corrections, such methods include physically-based and image-based approaches. The most commonly used physically-based models in environmental monitoring are 6S (Second Simulation of the Satellite Signal in the Solar Spectrum) and the MODTRAN-incorporated algorithm such as Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercube (FLAASH) and Quick Atmospheric Correction (QUAC). The majority of physically-based methods require several input parameters from in situ atmospheric measurements such as: the pressure, temperature, water vapour, carbon dioxide, ozone, oxygen, methane and nitrous oxide (Lu *et al.* 2002b; Mahiny and Turner 2007; Norjamäki and Tokola 2007).

The major limitation of physically-based methods is the need for detailed atmospheric information. Due to this limitation, image-based atmospheric correction methods are widely used as the approaches that do not require any in-situ atmospheric data (Yang and Lo 2000; Song *et al*. 2001). There are many image-based atmospheric correction methods, these include: dark object subtraction (DOS), the contrast reduction method (CRM) and the histogram matching. On the whole, studies have shown that DOS performs better than other image atmospheric correction methods in environmental change analysis, especially when there is a lack of sufficient atmospheric data. DOS assumes that dark objects exist in an image and “a horizontally homogenous atmosphere”, the impact of which is uniform throughout the study area. The assumption is that such objects (dark objects) have zero or near zero percent surface reflectance (Yang and Lo 2000; Lu *et al*. 2002b). Thus, the signal recorded by the sensor from these objects is as a result of atmospheric scattering. The method therefore, examines the observed brightness values in the dark object, subtracting them from all pixel values in each respective band.

In the present study, the dark object subtraction (DOS) and histogram matching methods will be applied to correct for atmospheric effects on Landsat images. The histogram matching method will be used to correct atmospheric effects on the images with variable haze. Both DOS and Histogram matching techniques (unlike MODTRAN and FLAASH) do not require in situ atmospheric data, which are not available in the Niger Delta.

3.3.4 Different Landuse Change Detection Methods: Non-Classification and Classification Approaches

Scientists have made great efforts in developing techniques to assess and monitor the rate of change in landuse on global, regional and local scales. Lu *et al*. (2004) categorised the remote sensing landuse change detection methods that have been used in the literature as in Table 3.3.

It is evident from general reviews of other studies, that the remote sensing landuse change detections methods could be predominantly grouped into two: non-classification and classification methods. This section therefore reviews commonly used non-classification and classification methods as related to the present study.

Table 3.3. The remote sensing landuse change detection methods categories, adapted from Lu et al, (2004).

Categories	Composition
Algebra	Change detection methods that make use of algebra approach include: Image Regression; Image Differencing; Image Ratioing; Vegetation Index Differencing; Change Vector Analysis (CVA) and Background Subtraction.
Transformation	The transformation category includes Principal Component Analysis, Tasselled Cap (KT), Gramm–Schmidt (GS), and Chi-Square Transformations.
Classification	This includes supervised, unsupervised and hybrid classification, and Post-Classification Comparison change detection.
Advanced models	In this category are Li–Strahler Reflectance Model, Spectral Mixture Models, and Biophysical Parameter Estimation Models.
Geographical Information System(GIS) approaches	These include overlaying methods and buffering methods.
Visual analysis	This category involves visual interpretation of multi-temporal image composite and on-screen digitizing of changed areas.

3.3.4.1 Non-classification Based Approaches to Change Detection

This section covers commonly used non-classification based approaches to landuse change detection. Such commonly used methods that will be discussed in this section include image regression; image ratioing; vegetation indices; Markov Chain, and Geographical Information System (GIS) approaches (Table 3.4). Therefore, the main objective of this section is to assess the relative merits and limitations of each of these approaches, based on an environment related to that of the Niger Delta.

Table 3.4. Commonly used remote sensing methods to assess vegetation degradation and some references.

Method	**Merits**	**Limitations**	**Major References**
Image Regression	It accounts for differences in reflectance mean and variance between dates and the image produced can be easily interpreted.	Since it is based on linearity assumption, this technique is not acceptable if a large proportion of the study area has changed between the two image dates.	Singh (1989), Song *et al.*(2001), McGraw (2009), Bhatta (2010).
Image ratioing	It reduces the effects of sun angle, shadow and topography on the images.	The results are not normally distributed.	Prakash and Gupta (1998), Lu *et al.* (2004), Bhatta (2010).
Vegetation indices	It is simple and easy to apply and is a means of getting vegetation change information for remote location.	Atmospheric conditions do have significant influence on the results.	Bannari *et al.* (2003), Matricard *et al.* (2010), Xie *et al.* (2010), Matricardi *et al.* (2010).
Change vector analysis (CVA)	It is flexible and easy to apply when using different types of datasets.	It is difficult to identify vegetation change trajectory using this method.	Chen (2002), Lu *et al.* (2004).
Markov Chain	It is possible to extract information which is not accessible using other change detection techniques.	Complexity of physical environment could affect the result.	Brown *et al.* (2000), Wang *et al* (2010).
GIS-base Change Detection Method	Provides convenient tools for the multi-source data processing and are effective in handling the change detection analysis using multi-source data.	Proper knowledge of GIS is needed before using this method in landuse change analysis.	Coppin *et al* (2004), Ellis and Porter-Bolland (2008), Salamin *et al.* (2010).

3.3.4.1.1 *Image Regression*

This method establishes the relationships between bi-temporal images. The model performs regression on the selected bands before implementing change detection: using regression function to subtract the previous regressed bands from the first band. In the process, this method identifies suitable bands and the thresholds to be used (Lu *et al*, 2004). The regression equation function can be defined as follows:

$$\boldsymbol{DX_{ij}^{k} = X_{ij}^{k}\,(t_2) - X_{ij}^{k}\,(t_1)} \qquad (3.1)$$

Where pixels from t_1 are assumed to be a linear function of t_2. From this equation, x is the pixel values at line i and column j. According to Singh (1989), it is possible to regress $X_{ij}^{k}\,(t_1)$ against $X_{ij}^{k}\,(t_2)$ using a linear regression function. This method accounts for the difference in the mean and variance between the pixel values for different periods of time. The merit of this method is that it reduces the effect of atmospheric, sensor and environmental differences between the two images obtained in a different periods of time.

The major limitation of this approach however is that this technique is not acceptable, if a large proportion of the study area has changed between the two image dates, since it is based on linearity assumption (Lu *et al*. 2004, Bhatta 2010).

3.3.4.1.2 *Image Ratioing*

The method involves dividing the radiance values from one or more image channels, by the radiance values of data in the same channels from different dates. Studies have shown that image ratioing is a relatively rapid means of identifying areas of change in vegetation coverage (Nelson 1983; Prakash and Gupta 1998; Lu *et al.* 2004). Prakash and Gupta (1998) reported further that the major advantage of this method is that it reduces the effects of sun angle, shadow and topography on the images. In image ratioing, images are compared pixel by pixel using the equation as follows:

$$\boldsymbol{RX_{ij}^{k} = \frac{X_{ij}^{k}\,(t_1)}{X_{ij}^{k}\,(t_2)}} \qquad (3.2)$$

Here, $X_{ij}^{k}\,(t_1)$ is the pixel value at line i and Column j for band k at a given time t_1, and is divided by the pixel value at line i and Colum j for band k at a given time t_2 . Thus, if the reflected radiation is nearly the same in each image then RX_{ij}^{k} =1 and this indicates no change. Whenever $RX_{ij}^{k} > 1$ or $RX_{ij}^{k} < 1$ this indicates the area of change, although, the sign of the value depends upon the nature of the changes between the two dates.

Lu *et al.* (2004) noted the distribution of the results from this method is usually non-normal. They observed that if the distributions are non-normal, and functions of the standard deviations are used to delimit change from non-change, the areas delimited on either side of the mode are not equal, thus making the error rates on either side of the mode not to be equal. As with other change detection methods, another limitation of image ratioing method is the selection of appropriate threshold values in the lower and upper tails of the distribution to represent changed pixel values. According to Bhatta (2010), the best way to achieve this is by selecting arbitrary threshold values and testing them to determine if the change detection was performed accurately. Prakash and Gupta (1998) applied the method in mapping environmental change in a coal mining area of Jharia coal field in India. They performed image ratioing with other methods, and were able to map landuse changes along with other methods such as image differencing and differencing of NDVI images. The result from their study showed that image ratioing is sensitive to misregistration, thus their study concluded that the results from image ratioing is not as accurate as results from other change detection methods.

3.3.4.1.3 Vegetation Indices

Vegetation indices are remote sensing measurements used to quantify vegetation cover, vigor or biomass for each pixel in an image (Ouyang *et al.* 2010). Vegetation indices use spectral bands that are sensitive to plants. The red and near-infrared bands are usually used in this method because of their sensitivities in detecting vegetal cover. The spectral bands may be added, divided or multiplied to produce a single value (Lu *et al.* 2004; Matricard *et al.* 2010; Xie *et al.* 2010). Over forty vegetation indices are found in the literature (Table 3.5), out of which only three (Ratio Vegetation Index, Transformed Vegetation Index and Normalized Difference Vegetation Index) are commonly applied to Landsat images.

Table 3.5. Some Vegetation Indices found in the literature.

Index	Initiator	Formula
Atmospherically Resistant Vegetation Index	Kaufman and Tanre, (1992)	$ARVI = \frac{(NIR - RB)}{(NIR + RB)}; \quad RB = R - \gamma(B - R)$
Adjusted Green Vegetation Index	Jackson *et al.*, (1983)	$AGVI = GVI - (1 + 0.018GVI)YVI - \frac{NSI}{2})$
Adjusted Soil Brightness Index	Jackson *et al.*, (1983)	$ASBI = (2.0\,YVI)$
Angular Vegetation Index	Plummer *et al.*, (1994)	$AVI = tan^{-1}\left\{\frac{\lambda_3 - \lambda_2}{\lambda_2}[NIR - R]^{-1}\right\} + tan^{-1}\left\{\frac{\lambda_2 - \lambda_1}{\lambda_2}[G - R]^{-1}\right\}$
Ashburn Vegetation Index	Ashburn, (1978)	$AVI = (2.0MSS7 - MSS5)$
Differenced Vegetation Index	Richardson and Wiegand (1977)	$DVI = (NIR - R)$
Enhanced Vegetation Index	Huete et al. (1999)	$EVI = G\,\frac{(NIR - R)}{NIR + c_1R - c_2B + L}(1 + L)$
Global Environment Monitoring Index	Pinty and Verstraete, (1992)	$GEMI = \cap\,(1 - 0.25\,\cap) - \frac{(R - 0.125)}{(1 - R)}$; $\cap = \left\{\frac{2(NIR - R^2) + 1.5NIR - 0.5R}{(NIR + R + 0.5)}\right\}$
Greenness Above Bare Soil	Hay et al, (1979)	$GRABS = (GVI - 0.09178BI + 5.58959)$
Green Vegetation Index	Kauth and Thomas (1976)	$GVI = (-0.283MSS4 - 0.660MSS6 + 0.388MSS7)$
Green Vegetation and Soil Brightness	Badhwar, (1981)	$GVSB = \frac{GVI}{SBI}$
Misra Green Vegetation Index	Misra *et al.*, (1977)	$MGVI = (-0.386MSS4 - 0.530MSS5 + 0.535MSS6 + 0.243MSS7)$
Misra Non Such Index	Misra *et al.*, (1977)	$MNSI = (0.404MSS4 - 0{,}039MSS5 - 0.505MSS6 + 0.762MSS7)$
Misra Soil Brightness Index	Misra *et al.*,	$MSBI = (0.406MSS4 + 0.600MSS5 + 0.645MSS6 + 0.243MSS7)$

	(1977)	
Misra Yellow Vegetation Index	Misra *et al.*, (1977)	$MYVI = (0.723MSS4 - 0.597MSS5 + 0.206MSS6 - 0.278MSS7)$
Modified SAVI	Qi et al., (1994)	$MSAVI = \frac{2NIR + 1 - \sqrt{(2NIR+1)^2 - 8(NIR - R)}}{2}$
Multi-Temporal Vegetation Index	Yazdani *et al.*, (1981)	$MTVI = (NDVI(date2) - NDVI(date1))$
Normalized difference Greenness Index	Chamard *et al.*, (1991)	$NDGI = \frac{(G - R)}{(G + R)}$
Normalized difference Index	McNairn and Protz, (1993)	$NDI = \frac{(NIR - MIR)}{(NIR + MIR)}$
Normalized difference Vegetation Index	Rouse (1973) Rouse *et al.*, (1974)	$NDVI = \frac{NIR - RED}{NIR + RED}$
Non Such Index	Kauth and Thomas, (1976)	$NSI = (-0.016MSS4 + 0.131MSS5 - 0.425MSS6 + 0.882MSS7)$
Perpendicular vegetation Index	Richardson and Wiegand, (1977)	$PVI = \frac{(NIR - aR - b)}{\sqrt{A^2 + 1}}$
Ratio Vegetation Index	Birth and McVey (1968)	$RVI = \frac{R}{NIR}$
Redness Index	Escadafal and Huete, (1991)	$RI = \frac{(R - G)}{(R + G)}$
Soil Adjusted Vegetation Index	Huete (1988)	$SAVI = \frac{(NIR - R)}{NIR + R + L}(1 + L)$
Soil Background Line	Richardson and Wiegand (1977)	$SBL = (MSS7 - 2.4MSS5)$
Soil Brightness Index	Kauth and Thomas, (1976)	$SBI = (0.332MSS4 + 0.660MSS5 + 0.675MSS6 + 0.262MSS7)$
Transformed Soil Atmospherically Resistant Vegetation Index	Huete and Liu, (1994)	$TSARVI = \frac{[a_{rb}(NIR - a_{rb}RB - b_{rb})]}{[RB + a_{rb}NIR - a_{rb}b_{rb} + X(1 + a^2{}_{rb})]}$

Transformed SAVI	Baret et al. (1989)	$TSAI = \frac{[a(NIR - aR - b)]}{[R + aNIR - ab + X(1 + a^2)]}$
Transformed Vegetation Index	Deering et al. (1975)	$TVI = \left(\frac{RED - NIR}{RED + NIR} + 0.5\right) 1/2$
Vegetation Index Number	Pearson and Miller, (1972)	$VIN = \frac{NIR}{R}$
Yellow Vegetation Index	Kauth and Thomas, (1976)	$YVI = (-0.899MSS4 + 0.428MSS5 + 0.076MSS6 - 0.041MSS7)$

Source: *Modified from Bannari et al. (1995),* Silleos, *et al.(2006),* Redowan and Kanan (2012).

Ratio Vegetation Index (RVI) is one of the earliest vegetation indices applied in remote sensing analysis. The ratio of the near infrared (NIR) band to a red band can indicate vegetation as below:

$$\boldsymbol{RVI = \frac{RED}{NIR}} \qquad (\mathbf{3.3})$$

RVI has similar limitations and advantages (Bhatta 2010). The main advantage of RVI is that it enhances the contrast between the vegetation and the ground, and it reduces the effects of varying illumination conditions. However, Bannari *et al.* (2003) has reported the limitation of RVI to be its sensitivity to the ground optical properties and its sensitivity to atmospheric effects thus makes its discriminating power weak when the vegetative cover is less than 50%.

Out of all the vegetation indices, NDVI is the most widely applied to monitor vegetation change on regional and local scales. NDVI combines two channels (NIR and RED) in a normalised ratio, which makes it possible to differentiate vegetation cover signal from other objects as shown below.

$$\boldsymbol{NDVI = \frac{NIR - RED}{NIR + RED}} \qquad (\mathbf{3.4})$$

The lowest value represents the difference between the red and NIR, and especially indicates that the red value is higher than the NIR signal. A higher value signifies a larger difference between the red and near infrared radiation recorded by the sensor (Bannari *et al.* 1995; Lu *et al.* 2004; Xie *et al.* 2010). The value of this index ranges from -1 to +1. It has been shown in the literature that -1 value is generally from ice or cloud on the image, zero values stand for areas with no vegetation, and +1 value signifies the maximum potential density and greenness of leaves. The common range for green vegetation is 0.2 to 0.8. Studies have shown that NDVI values that are less than zero do not have any ecological meaning, therefore, the index should rage from 0.0 to 1.0 (Xie *et al.* 2010; Redowan and Kanan 2012).

However, the major limitation of NDVI method is that it is influenced by environmental factors such as nature of soils; cloud cover and atmospheric effects (Bannari *et al.* 1995; Maxwell and Sylvester 2012; Redowan and Kanan 2012). For instance, Matricard *et al.* (2010) noted that NDVI values tend to change as a result of soils moisture changes. Soil reflectance is a direct function of water content; therefore, they tend to darken when wet. Since the spectral response to moistening is not exactly the same in the two spectral bands, the NDVI is affected. Cakir *et al.* (2006) further argued that NDVI differencing is not effective in a region where vegetation cover is low because of the predominance of background effects. Likewise, cloud and other atmospheric conditions also have significant influence on NDVI. For example, Van Leeuwen *et al*. (2006) and Ji and Peters (2007) noted that slight changes in NDVI differencing values between two dates occur as a result of differences in atmospheric conditions, with increased haze leading to a reduction in NDVI. Thus, the method needs to be applied to images acquired under clear sky conditions and atmospheric correction is essential.

The Transformed Vegetation Index (TVI) was derived from NDVI. This index is usually used principally to eliminate negative values, and to normalize the NDVI histogram. The commonly used TVI derived from Landsat MSS data is given as:

$$\boldsymbol{TVI} = \left(\frac{\boldsymbol{RED-NIR}}{\boldsymbol{RED+NIR}} + 0.5\right)^{\mathbf{1/2}} \qquad \mathbf{(3.5)}$$

Where 0.5 is a bias term that automatically prevents negative values under the square root for most images. TVI was developed in order to avoid operating with negative NDVI values, correct NDVI values that estimated the Poisson distribution; and to create a normal distribution. However, studies have shown that there are no differences between NDVI and TVI in terms of image output or active vegetation detection (Silleos *et al.*2006; Maxwell and Sylvester 2012; Redowan and Kanan 2012). The majority of these studies have shown that the TVI should be used with great caution because this index could turn out to be more sensitive to a number of factors such as cloud condition, atmospheric and soil characteristics of the study area.

Mostly to assess vegetation change, vegetation index differencing is commonly applied usually by subtracting the vegetation index images of one date from another. The lower and higherends of the tails of the vegetation index difference-image histogram detect change in the vegetation. Several studies have used vegetation index differencing to assess vegetation change and it has often been found to be better than other methods (Bannari *et al.* 1995; Lu *et al.* 2004; Xie *et al.* 2010; Matricard *et al.* 2010; Ouyang *et al.* 2010). For instance, Matricard *et al.* (2010) employed this method to assess tropical forest degradation caused by logging and fire, using Landsat imagery and found it a reliable method to assess change in vegetation.

In this study, NDVI will be employed to monitor vegetation degradation in the Niger Delta. The review above has shown that this method is the most commonly applied change detection technique to assess vegetation degradation, because it is generally effective while simple and easy to apply. The methodological approach used in this study is detailed in the next chapter.

3.3.4.1.4 Geographical Information System (GIS) approaches

Recently, Geographical Information System (GIS) methods have been used in LUCC detection monitoring. GIS is not a new development, it is only recently that it has gained widespread acceptance as a tool to assess landuse change. As noted by Coppin *et al.* (2004), application of GIS methods in landuse change detection has “enabled the delivery of change maps, derived from any descriptive change model, in a timely fashion, at scales that are consistent with ecosystem management objectives”. Presently, classified images from remote sensing analysis are viewed as inputs to GIS and at the same time, GIS data layers have been used as ancillary inputs to classification of remote sensing data. The GIS-based change detection methods include application of overlaying and buffering approaches available in GIS environment (Wang *et al.* 2010).

Overlaying approach involves integration of different data layers, which may be raster or vector data (Salamin *et al.* 2010). The process includes both visual and analytical operations in order to join one or more data layers physically. In landuse change monitoring, overlaying operation can integrate data on soil types, slope, forest and wildlife, climate dataset, population and infrastructural development, among others (Ellis and Porter-Bolland 2008; Salamin *et al*. 2010). On the other hand, buffering operation is used in landuse change assessment to create a zone of a specified width around a landuse area of interest (Ringrose *et al*. 1996). These buffered layers can be used in querying and determining which landuse occurs, either within or outside the landcover defined buffer zone. According to Coppin *et al.* (2004), application of overlaying and buffering methods needs a prior knowledge of the study area (e.g. original ecosystem status, location, size, relationship with other cover types, shape, socioeconomic data, etc.), to direct and support the classification of image and change detection analysis.

GIS approaches have shown many advantages over other landuse change detection methods. According to Lu *et al.* (2004), application of GIS approaches in landuse monitoring “provides convenient tools for the multi-source data processing and are effective in handling the change detection analysis using multi-source data”. However, for better implementation of GIS approaches in LUCC detection analyses, it is necessary that more research should focus on integration of GIS and remote sensing techniques (Wang *et al*. 2010). Therefore, the present study will integrate GIS and remote sensing techniques in assessing landuse change in the Niger Delta of Nigeria. This approach is believed to provide a high-quality means of measuring the extent and pattern of changes over a period of time. The review above implies that application of GIS in landuse change study offers an efficient and speedy approach for mapping of basic landuse types and drivers of landuse change over large areas.

3.3.4.2 Classification Methods for Landuse Change Detection

The overall aim of any classification technique is to systematically classify pixels in an image into landuse classes. This categorisation of pixel is possible because different objects in an image manifest different radiance values, due to variation in their reflectance properties (Lillesand and Kiefer 2000). Classification of satellite imagery for landuse change detection is a complex process because many factors need to be considered, such as: determination of training samples; selection of a suitable classification approach; post-classification processing and accuracy assessment. Lu and Weng (2007) noted that classification of satellite imagery varies with the purpose of the research and the context of their use.

Table 3.6. Widely used methods in landuse change detection and some major references.

Category	Widely used Techniques	Major References
UNSUPERVISED CLASSIFIER	K-means ISODATA	Gao and Liu (2010); Jeyanthi and Kumar (2010); Ouyang *et al.* (2010) Akgn *et al.* (2004); Lu and Weng (2007); Xie *et al*. (2010).
SUPERVISED CLASSIFIER: **Non- Parametric Supervised Approach**	Parallelepiped Spectral Angle Mapper Neural Network Support Vector Machine Decision Tree	Xiang *et al.* (2005); Foody and Mathur (2004); Collins *et al.* (2004); Haapanen *et al.* (2004); Chan *et al.* (2001);Lu and Weng (2007); Perumal and Bhaskaran (2010); Estes *et al.* (2012).
Parametric Supervised Approach	Minimum Distances Mahalanobis Distance Maximum Likelihood	Xiang *et al.* (2008);Akgn *et al.* (2004); Perumal and Bhaskaran (2010); Akgn *et al.*(2004); Otukei and Blaschke (2010); Lambin *et al.*(2001); Ahmad (2012).
HYBRID CLASSIFIER: **Object-oriented**	eCognition	Guo *et al.* (2007), Liu and Xia (2010).
POSTCLASSIFICATION COMPARISON	Calculate class statistics and change detection statistic. Classify rule images, clump, sieve, and combine classes.	Singh (1989); Matricardi *et al.*(2010); Almutairi and Warner (2010); Matricardi *et al.*(2010); Xie *et al.* (2010); Estes *et al.* (2012); Patarasuk and Binford (2012).

Selection of appropriate classification methods has been the central focus of the research among remote-sensing scientists. Generally, classification methods which are commonly used in the literature can be grouped into three categories: unsupervised; supervised and hybrid classification methods. In the following section, a number of widely used classification methods are discussed. Table 3.6 presents the category of methods used to assess landuse change and some key references.

3.3.4.2.1 Comparing Different Image Classification Methods Used to Assess Landuse Change

Unsupervised classification examines and aggregates a large number of unknown pixels into a number of classes, based on natural groupings present in images. This method does not make use of analyst-specified training data in the process, whereas, the supervised classification method uses analyst-specified and predetermined training data to perform image classification (Lillesand and Kiefer 2000). Supervised classification works by identifying sample sites (known as training data), which are used to compile spectral attribute values for each object of interest in an image. Each pixel in the image is then compared numerically so as to classify them according to statistically similar categories (Gao and Liu 2010).

Different algorithms have been developed to perform unsupervised classification of satellite images. For example, K-mean and ISODATA are widely-used unsupervised classification methods applied in landuse change studies (Xie *et al.* 2010; Ouyang *et al.* 2010). The K-means method performs image classification by developing K-cluster centres (sometimes called centroids), the number of which is usually derived from a priori information. The algorithm randomly selects a cluster mean, then each pixel is assigned to the cluster to which it is most similar. To classify remote sensing image, each pixel is then categorised into the closest centriod, based on the distance between the cluster means. The centriods are then recalculated and the process iterated until convergence, a point when centriods no longer change is reached (Jeyanthi and Kumar 2010; Ouyang *et al*. 2010). The ISODATA classification algorithm works in a similar way (Gao and Liu 2010). The only difference is that ISODATA allows for different number of clusters, while K-mean is based on the assumption that the number of clusters can only be known in advance.

Several studies have reported the limitations of unsupervised classification methods (Akgn *et al.* 2004; Xie *et al.* 2010). Unsupervised Classification methods are entirely data-dependent, and the user not always needs to only specify the number of classes in advance. As a result, the approach is sensitive to data noise, since a small number of noises can easily affect the cluster mean value. This may result in error, important classes may be missed during classification, which may not occur if a supervised method is adopted (Lu and Weng 2007; Ouyang *et al.* 2010). This misclassification, according to Campbell (2002), might be because unsupervised classifiers usually identify spectrally homogenous classes within the data that may not correspond to information needed by the analyst. As a result of this major limitation of misclassification, many scholars have been using supervised classification approach.

3.3.4.2.2 Parametric and Non-parametric Supervised Classification Techniques

Different approaches have been used to perform supervised classification in landuse change detection. Lu and Weng (2007) grouped these approaches into two major classes: Parametric supervised classification techniques (such as Minimum Distances, Mahalanobis Distance and Maximum Likelihood) and Non-parametric supervised classification techniques (such as Parallelepiped, Neural Network, Decision Tree, Support Vector Machine and Spectral Angle Mapper Methods). Parametric classification techniques are based directly on statistical methods. The approach is based on the assumption that the distribution of the sample pixel is normal in all bands. This method has the advantage of assigning every pixel into a class, in view of the fact that the parametric decision function is continuous. On the other hand, the non-parametric supervised classification method is not based on an assumption about the distribution of data (i.e that the data are normally distributed), and it is not also based on statistics, but image classification is done through discrete partitioning of data. Pixels are classified into classes, based on their existence inside or outside the feature space partitions (Gao and Liu 2010; Perumal and Bhaskaran 2010). This approach has the advantage of being independent of the sample data properties.

An example of non-parametric classification approach is the parallelepiped classifier. Parallelepiped classifier performs image classification based on maximum and minimum pixel values in the training data (Lu and Weng 2007), whereby each pixel is classified into a class if and only if its band radiance falls within the specified range defined by that class. Xiang *et al.* (2005) noted that this approach is based on a simple logical rule-based algorithm, which is easy to perform, but Chen (2002) found out that this approach has poor accuracy. Furthermore, Perumal and Bhaskaran (2010) have reported that overlapping of classes occurs when using this method, and often, a pixel does not fall into any of the classes. Because of these limitations, many studies have used other non-parametric supervised methods which are more accurate as outlined below.

Other examples of non-parametric classification approaches are Spectral Angle Mapper (SAM), Neural Network (NN), Decision Tree (DT) and Support Vector Machine (SVM). SAM performs classification by matching pixels into a reference spectra using an n-dimensional angle. Perumal and Bhaskaran (2010) noted that SAM classifies an image by determining the spectral similarity, which it does by calculating the angle between image spectra and reference spectra, using a minimum angle approach. It has been reported in the literature that SAM is insensitive to illumination, since the algorithm uses only the vector direction and not the vector length (Chen 2002). NN is another example of non-parametric classification approach, and it consists of an interconnected root node with several internal nodes and terminal nodes. These techniques operate in a series of layers (input layers: at least one hidden layer; and output layers) and use algorithms such as the standard back-propagation algorithm to train the network (Chen 2002; Lu and Weng 2007). Alternatively, DT uses decision rules to perform classification of pixels, and consists of several binary decisions which are used to determine the correct classes for each pixel. Otukei and Blaschke (2010) explained that decisions are usually based on available information on pixel characteristics of the dataset, and each node uses a decision rule to classify data into the defined classification framework. Moreover, SVM is based on linear learning model that uses and takes a set of input data and predicts which classes the pixel belongs to, using a linear separating hyperplane that separates classes of interest (Schwert *et al*. 2013). In a two class example, the SVM classifier operates by locating a hyper plane that maximizes the distance between two-classes, from the members of each class to the optimal hyper plane. SVM is a binary classifier which assigns pixel a class from one of two possible labels (Mountrakis *et al*. 2011; Schwert *et al*. 2013).

Recent studies have evaluated the performance of SVM in landuse classification (Mantero *et al*. 2005, Tuia *et al*. 2009; 2011; Mountrakis *et al.* 2011) and found out that it is usually more accurate than the traditional classification methods discussed above. Some studies found that the method, not only capable of working with small training data sets, but also produces higher classification accuracy (Mantero *et al*. 2005; Schwert *et al*. 2013). On the other hand, some other studies concluded that the method does not make use of all available training sample in the analysis. Likewise, Mountrakis *et al.* (2011) noted that it resulted in slower operation compared to other methods.

In general, it has been reported in the literature that the non-parametric methods are easy to perform and can give good results, especially when characteristics of image data are known in advance. On the other hand, studies have shown that non-parametric classification methods are sometimes not accurate for vegetation and urban classification (Akgn *et al.* 2004; Xiang *et al.* 2005; Schowengerdt 2006; Lu and Weng 2007). Furthermore, Schowengerdt (2006) has noted that unlike parametric classifiers, it is not possible to properly estimate classification error from non-parametric classifiers. Schowengerdt (2006) further argued that difficulties often arise when interpreting the behaviours of non-parametric classifiers (especially NN), because of the dependence of their results on the training conditions.

As a result of the limitations of non-parametric classifiers, many studies have used parametric supervised classification methods. Popular parametric algorithms include: minimum distance, mahalanobis distance and maximum likelihood, out of which.the maximum likelihood algorithm is widely used, and is based on Bayesian probability theory. The algorithm performs classification by using training data to calculate mean and covariance of the classes, and using this to calculate the Bayesian probability. Pixels are then classified to the class they have the highest probability of belonging to (Akgn *et al.* 2004; Perumal and Bhaskaran 2010). It has been reported by previous studies that maximum likelihood gives more accurate results than parallelepiped, minimum distance and mahalanobis distance methods (Lu and Weng 2007, Akgn *et al.* 2004; Otukei and Blaschke 2010). The main merit of ML over other classifiers is that it considers not only the mean or average in classification operation, but also the variability of brightness values in each class. Besides, ML is flexible and useful under any condition, and it provides probably the most effective means of landuse classification, given the limitation of other classifiers. This is because ML classifier quantitatively evaluates both the variance and covariance of the category spectral response patterns when performing classification. The classifier delineates ellipsoidal equi-probability contours in the scatter diagram and this expresses the sensitivities of the classifier to covariance (Lillesand and Kiefer 2000; Gao *et al*. 2010). It has been earlier reported also in the UK LCM (2007) report and other literature that ML is more accurate than other classification methods of landuse change detection (Lu and Weng 2007, Perumal and Bhaskaran 2010, Morton *et al* 2011, Hansen and Loveland 2012). In general, the results from the studies by Akgn *et al.* (2004) and Xiang *et al.* (2005) have further revealed that parametric supervised classification methods are to some extent, better than non parametric ones.

Minimum distance classification uses the mean value of the training data in each band for each class, and performs landuse classification by calculating the distance between the mean vectors for each class. The mahalanobis distance uses a similar strategy, but has the advantage that it also considers the variance of each class (Lillesand and Kiefer 2000). Lillesand and Kiefer (2000) and Perumal and Bhaskaran (2010) have noted the main limitation of these methods that covariance data are not used in minimum distance (though mahalanobis distance does consider variance), thus models are symmetric in their spectral domain, so some classes may not be well modelled.

Another approach to change detection is the multi-temporal classification approach. This approach uses different stacked images, created from the bands from multiple dates of imagery, to form a single image. This method is performed by compiling two or more temporal images into a composite image, and training both unchanged and changed classes within the classification process (Turker and Arikan, 2005; Joshi *et al*. 2006; Bhatta 2010). This stacked image is then classified using traditional image classification techniques to identify the major landuse classes present in the study area, which has shown in the literature to be an effective method of change detection. Some studies have even argued that this classification technique can increase classification accuracy (Van Niel and McVicar 2004; Yuan *et al*. 2005; Turker and Arikan, 2005). Despite these benefits, many studies, including the present study, do not use this method because it has several limitations. Review of literature has shown that the extent to which multi-temporal classification approach improves change detection analysis is a function of the number and timing of the various dates of images used. In Niger Delta for instance, acquiring large number of Landsat data during the same season (dry or wet) is not possible, due to enormous cloud cover as discussed in chapter two. This makes it difficult to use multi-temporal classification approach in this study. Using this method though, training is difficult and it is difficult to identify comprehensively what has changed, and changed to what?. Even if all bands from each data are used in the analysis, the complexity of the classification can be quite great, and there may be substantial redundancy in their information content. Thus, the resulting image from this approach is often difficult to interpret and on many occasions, not effective for cartographic representation. As a result, many studies still prefer using traditional classification methods (Baldi *et al*. 2006; Bhatta 2010; Lasanta and Vicente-Serrano 2012).

3.3.4.2.3 Hybrid Classifiers

In addition to the methods discussed in the section above, studies in recent years have developed and used hybrid classification method (Camplbell 2002). Hybrid classifiers share characteristics of both unsupervised and supervised classification methods. Typical example of hybrid method is an object-oriented method (Yu *et al.* 2006; Guo *et al.* 2007; Hay and Castilla 2008; Liu and Xia 2010), and is based on objects in an image. Object-oriented method works by dividing the satellite image into segments (i.e objects), which symbolize a homogenous unit on the ground (Liu and Xia 2010). Multi-resolution segmentation is often used to create hierarchical networks of image objects for classification. This segmentation is based on overall resolution of the pixels that make up the object and the scale of the expected object. Using this approach, only homogenous image objects are extracted during the segmentation, and these are then classified, instead of classifying each pixel individually as in pixel-based classifications (Guo *et al.* 2007). The main advantage of object-oriented method is that it can be more easily integrated in vector GIS than the pixel-based classification approach which produces raster maps (Yu *et al.* 2006).

However, the object-oriented method has some limitations. Hay and Castilla (2008) argue that it is only effective when very high resolution image data (such as *QuickBird and Ikonos*) are used in assessing landuse and landcover change. It is extremely difficult to segment some objects in Landsat image, because at the 30 meter spatial resolution, many of the pixels at the boundaries are mixed. A study by Liu and Xia (2010) likewise confirmed that object-oriented method is prone to over-segmentation and under-segmentation errors, when delineating objects using Landsat imagery. Another problem is that during segmentation of objects, one object may be partitioned into multiple smaller image objects, which leads to over-segmentation. Similarly, under-segmentation error occurs when dissimilar semantic objects are grouped into one outsized image object (Guo *et al.* 2007; Hay and Castilla 2008).

At first, the present study tested six classifiers using field survey data collected from the Niger Delta, to determine which method is most appropriate. The methods evaluated are Parallelepiped Classifier (PL), Minimum Distance (MD), Mahalanobis Distance (MHD), Spectral Angle Mapper (SAM), Support Vector Machine (SVM) and Maximum Likelihood (ML). Selection of appropriate classification method for this study was based on the result of the tests. This test was discussed in details in the next chapter, while the results of accuracy tests of these methods are presented in chapter five.

3.3.4.3 Post-classification Comparison of Landuse Change Analysis

After the landuse classification processes, post-classification comparison is usually employed in order to detect the landuse change that occurs between the two dates of classified images (Singh 1989; Matricardi *et al.* 2010; Almutairi and Warner 2010). According to Singh (1989), post-classification comparison performs landuse change detection by coding results from classification for different dates and producing change maps that demonstrate a matrix of changes. When performing post-classification comparison each date image is independently re-classified to a number of classes of landuse maps. The class maps are then overlaid and compared on a pixel-by-pixel basis. A transition matrix is then used to summarize this per-pixel comparison, which shows possible landuse change and presents areas of change in each class (Bhatta 2010). This method is simple and easy to use and its conceptual simplicity is a reason of its wide application. Many studies have been conducted using simple overlay of classification maps, but it has been found out that such an approach is prone to boundary errors, particularly when data from different sensors are used (Singh and Harrison 1985; Xie *et al.* 2010).

The major advantage of post- classification comparison over other methods, according to Singh (1989) and Xie *et al.* (2010) is that images from two dates can be separately classified and this approach also minimizes the problem of normalizing for atmospheric or sensor differences between two images of different dates. In view of this, post-classification comparison will be used in the present study to monitor landuse change in the Niger Delta of Nigeria. This approach will help in identifying the percentage change, trend and rate of change in landuse over the study periods. Part of post classification processing will include calculation of the average annual percentage change in the Landuse in the Delta. This will provide better understanding of the inter-annual rate of change in landuse over the period of study.

3.3.5 Accuracy Assessment Techniques

Accuracy assessment is an important step in determining the quality of landuse classification (Powell *et al*. 2004; Lu *et al.* 2005; Matricardi *et al.* 2010). This is because errors can be high and in applying any landuse change detection methods, one needs to know the sources and scale of the errors. Apart from error from the classification itself, other sources of errors include: position errors resulting from the registration, interpretation errors, and errors caused by poor quality of training data (Ellis and Porter-Bolland 2008), all these errors have cumulative impacts on the landuse classification accuracy. Therefore, the users of landuse maps need to know how accurate the product is for effective usage (Salami *et al*. 2010; Wang *et al* 2010).

The error matrix approach is the most widely used in accuracy assessment of landuse change assessment (Foody 2002b; Wang *et al.* 2010), and is sometimes referred to as confusion matrix. The error matrix is used to display statistics used for assessing image classification accuracy by showing the degree of correct classification and misclassification among landuse classes (NRC 2005; Wang *et al.* 2009; Otukei and Blaschke 2010). Many different classification accuracy assessment methods can be derived from this error matrix and a wide variety have been used in landuse change studies. The most widely used ones are the overall accuracy, the producers' accuracy, the users accuracy and the Kappa coefficient (Ellis and Porter-Bolland 2008; Otukei and Blaschke 2010; Matricardi *et al.* 2010; Wang *et al.* 2010).

Overall accuracy measures the percentage of correctly classified pixels. This method is a good measurement of the accuracy of a classification scheme, because it is not biased towards the smaller classes (NRC 2005). Overall accuracy can be expressed as follows:

$$\boldsymbol{Overall\ accuracy} = {\left(\sum^{\boldsymbol{i=landuse\ classes}} \boldsymbol{Ci}\right)}\Big/_{\boldsymbol{C++}} * \mathbf{100} \qquad (\mathbf{3.6})$$

Where C_i is the major diagonal for all correctly classified pixels, according to ground truth data, and $C{+}{+}$ is the total number of pixels. Thus, off-diagonals signify misclassified pixels (Otukei and Blaschke, 2010).

Producers' accuracy was achieved by calculating the ratio of the number of correct pixels for a class, to the actual number of ground truth data for that class (NRC, 2005). Producers' accuracy gives an idea about what percentage of a particular class was correctly classified. The main difference between User and Producers' accuracy is that: User accuracy is calculated along the row while producers' accuracy is calculated along the column of a confusion matrix. Previous studies have shown that both user and producers' accuracy are good ways of calculating accuracy per class (Otukei and Blaschke 2010; Matricardi *et al.* 2010; Salami *et al.* 2010; Wang *et al.* 2010). For example, Wang *et al.* (2010) noted that both methods are suitable measurements of per-class landuse classification accuracy, because they are not biased towards the smaller classes.

The Kappa coefficient measures the agreement, beyond chance, of a classification and ground-truth (NRC 2005). It is represented by the symbol kappa *hat* or *k hat* as shown in the equation below:

$$\hat{\boldsymbol{K}} = \frac{\boldsymbol{N} \sum_{i=1}^{r} \boldsymbol{X}_{ii} - \sum_{i-1}^{r} (\boldsymbol{X}_{i+} \times \boldsymbol{X}_{+i})}{\boldsymbol{N}^2 - \sum^{r} (\boldsymbol{X}_{i+} \times \boldsymbol{X}_{+i})} \qquad (\mathbf{3.7})$$

Where $\hat{\boldsymbol{K}}$ (kappa value) indicates how accurate the classification output has been accounted for, after this chance; r is the number of rows in the confusion (error) matrix; x_{ii} is the number of observations in row i and column i (on the major diagonal); x_{i+} is the total observations in row i; x_{+1} is the total observations in column i; and N is the total number of observations included in the matrix. Out of all the accuracy assessment methods, several studies have shown that Kappa analysis is a better method for analysing a single error matrix and for comparing the differences between various error matrices.

Accuracy assessment can be affected by the type of reference data used to perform accuracy assessment (NRC 2005; Stehman 2012). A number of approaches have been used in the literature to assess accuracy of landuse classification from remote sensing data, but in general, scholars perform accuracy by comparing the classification results with some other reference data. Such reference data include: higher resolution satellite images; aerial photo interpretation and data from ground truth (field observation). The majority of these studies show that virtually all reference data contain some degree of errors, but data from ground truth is preferred, if higher resolution satellite images are not available. Overall accuracy and the Kappa statistical approaches will be used in this study to assess the accuracy of landuse change maps produced. Ground truth data from field survey will be used to perform accuracy assessment. These methods of accuracy assessment will be used to measure the agreement of classification results with the ground truth information. Details about classification, post classification and accuracy assessment methods used in this study is presented in chapter four.

3.3.6. Remote Sensing of Oil Spill Detection

Remote sensing has the potential to become an important tool for assessment of oil spills and their impacts on the environment. As oils spills are a large problem in the Niger Delta, detecting and monitoring them from remote sensing is an important application. Several sensors and methods have been used to evaluate and monitor oil spills, both on water and land. On water, studies have shown that oil has a higher surface reflectance than water (Brown *et al.* 1996; Taylor 1992; Salem and Kafatos 2001). The majority of the studies looking at oil on water have used visible and infrared sensors to examine oil spills. Cameras and spectrometers are commonly used optical sensors. This is because they have the benefit of low cost, but the major limitation of visible sensors is their inability to detect oil at night as they depend on the reflectance of sunlight (Fingas and Brown, 2000; Hu *et al.* 2003). A study by Hu *et al.* (2003) revealed how oil spills can be assessed and monitored using MODIS data, and demonstrated its potentials for daily monitoring of the coastal zones, looking for large oil spills. The major limitation of this data is low spatial resolution and cloud cover. In recent years, studies have also used Synthetic Aperture Radar (SAR) to detect and monitor oil spills, especially in the North Sea (Costa 2004; Souza Filho *et al*., 2005; Silva *et al*., 2009). SAR is capable of observing oceans at night, and capturing images during any climate conditions, even during cloudy weather.

On land, Brown *et al.* (1996) noted that oil has no specific reflectance characteristics that distinguish it from the background. The majority of studies on oil spills on land have used spectral reflectance in the visible and infrared (0.7-14) µm interval in the electromagnetic spectrum (Bianchi *et al*. 1995; Fingas and Brown 1997; Hu *et al.* 2003; Jha *et al*. 2008). For example, a study by Fingas and Brown (1997) observed that oil spill detection is possible on land in the thermal infrared, because oil absorbs solar radiation and re-emits a portion of this energy as thermal energy. The study found out that thermal sensors usually observe thick oil slicks as hot, intermediate thickness of oil as cool, while thin oil is not possible to detect on land.

Likewise, Landsat data has been used to assess oil spills by many studies (Table 3.7). Some of these studies compared Landsat data with other sensors. For example, Bentz and de Miranda (2001) compared the performance of RADARSAT-1 and Landsat-TM in detecting oil spill incidence in Guanabara Bay, Brazil. The result from the study, like majority of other studies in Table 3.7, showed that low spatial resolution, cloud cover, haze and the 16-day revisit schedule of Landsat prevent its use for effective oil spill monitoring (Gonçalves *et al.* 2009; Rocha-Oliveira *et al.* 2008).

The majority of the studies shown in Table 3.7 used classification and visual interpretation methods. The classification schemes were based on supervised classification (Bentz and de Miranda 2001; Teixeira and Souza-Filho 2009) and unsupervised classification (Gonçalves *et al.* 2009) approaches, while visual interpretation was used to aid in identifying and understanding the physical and biological characteristics of the oil spill environment (Rocha-Oliveira *et al.* 2008; Silva *et al.* 2010). The major challenge of this method is how to discriminate oil spill and 'look-alike' regions. Some of these studies used data collected from the field to help discriminate possible oil spill and 'look-alike' features (Araújo *et al*. 2007; Gonçalves *et al.* 2009; Teixeira and Souza-Filho 2009).

Table 3.7. Studies that used Landsat to estimate oil spill.

Author	Data	Method
Araújo *et al*. (2007)	Landsat 7 ETM+ Aerial photography	Visual interpretation, field data collection
Bentz and de Miranda (2001)	RADARSAT-1 and Landsat-TM	Classification, visual interpretation
Bellotto and Sarolli (2008)	Landsat 7 ETM+	Visual interpretation, field data collection
Carvalho and Gherardi (2008)	Landsat 7 ETM+	Classification, visual interpretation
Fiscella et al. (2000)	Landsat 5 TM, Landsat 7 ETM+	Classification
Gonçalves *et al.* (2009)	Landsat 7 ETM+, Radarsat 1.	Automatic classification
Rocha-Oliveira *et al.* (2008)	Landsat 7 ETM	Visual interpretation, field data collection
Souto *et al.* (2006)	Landsat 5 TM, Landsat 7 ETM+, Aerial photography	Automatic classification, Normalized Difference Vegetation Index, visual interpretation
Souza, *et al*. (2005)	Landsat 5 TM, Landsat 7 ETM+, Spot, Cbers-2, Ikonos.	Visual interpretation, field data collection
Silva *et al*. (2008)	Landsat 7 ETM+	Visual interpretation
Silva *et al.* (2010)	Landsat 7 ETM+, Cbers-2.	Visual interpretation, field data collection
Teixeira and Souza-Filho (2009)	Landsat 5 TM, Landsat 7 ETM+.	Classification, visual interpretation, field data collection

Another method used in the literature is change detection using band ratios. This method is carried out by calculating the ratio of two bands for two different periods of time and then differencing them (Souto *et al.* 2006). One of the merits of this method is that the specific bands can emphasize oil spills and reduces the effects of sun angle, shadow and topography on the images (Srivastava and Singh 2010). The commonly used band ratio method is change detection using the Normalized Difference Vegetation Index, which is widely applied to

Landsat images to monitor vegetation change resulting from oil spill incidents (Souto *et al.* 2006). The main challenge of this method, also according to Souto *et al.* (2006), is that no-change areas can be treated as having slowly varying background grey levels, in the context of looking for changed areas with large differences in and around oil spill areas.

Most studies that use currently operational medium resolution optical sensors (e.g. Landsat) concluded that remote sensing of oil spills does not offer much potentials for operational oil spill monitoring at present. There are problems relating to timing, frequency of overpasses and spatial resolution (Silva *et al.* 2010). Landsat for example, can only revisit the same location after 16 days, which precludes systematic temporal monitoring of oil spills. Another challenge of using Landsat, like other optical sensors, is the need for clear skies to perform optical work. The likelihood of overpasses and the clear skies occurring at the same time of an oil spill is low (Rocha-Oliveira *et al.* 2008). This problem is not peculiar to optical sensors, all satellite data suffers from problems of either resolution or timeliness or both (Fingas and Brown 1997). Another major challenge of using satellite data in oil spills is how to distinguish oil slicks from other natural phenomena (oil spill look-alike features), as some land features may appear like oil on the image. On water, such look-alike features include natural films/slicks and grease ice (Jha *et al*., 2008; Boulhosa and Souza-Filho, 2009), while such look-alike features on land are wetlands and dark soils (Bentz and de-Miranda, 2001). Given that both of these features are common in the Niger Delta, it does not bode well for the method.

3.4 Linking Remotely Sensed and Social Data in Landuse Change Assessment

What is apparent from the literature is that few social researches outside the field of geography have applied spatial and temporal explicitness provided by remote sensing data in their studies. Nonetheless, social survey data sometimes consist of geographical details that could facilitate linking social science data and remotes sensing data (Liverman *et al.* 1998). Though, social research primarily concerns with why social issues happen than where they happen, it is only recently that the spatial and temporal characteristics of remote sensing data have been receiving attention in social research (Petit *et al.* 2001; Rogan *et al.* 2002; Wang *et al.* 2009; Avitabile *et al.* 2012). This section of the study thus discusses the main benefits of linking remote sensing dataset with social data in landuse change assessment.

Social data might help in the validation and better interpretation of landuse change using remote sensing. In landuse change detection, ground truthing is usually carried out for validation of the remote sensing analysis. Usually, some ground truthing involve classifying landuse remote observations into details of social landuses, thus, detailed validation of such social landuse classes depend on input from social research (Ahmad 2012; Avitabile *et al.* 2012). For example, based on social uses, some trees can be classified as productive agroforestry, some as orchard, some as park land, while some area of land are classified as suburban landscaping (Liverman *et al.* 1998). Therefore, for appropriate validation of such landuse classification, the researcher might not only depend on findings from field ground truthing, or from remote sensing analysis, but also utilize social information to make these distinctions, and for better interpretation of remote sensing results.

On the other hand, it is noticeable from literature that remote sensing provides time series data on socially related issues. Combining both data sources might help in both social and remote sensing investigations, in order to trace relationships of cause and effect, which is not possible using social experimental method only. Thus, as social data is useful for validation and better interpretation of remote sensing analysis, so also data from remote sensing provides time-series data of good comparability with long-time processes of human-environment interaction (NRSA 1982; Liverman *et al.* 1998; Rogan *et al.* 2002; Wang *et al.* 2009). Though, it is apparent from literature that both social and remote sensing data have their limitations, combining them in landuse change assessment might provide a better and bigger picture of the drivers and the rate of change. Amalgamation of social and remote data might also yield a deeper understanding of the landuse change issues. For example, it is possible to measure extent of agricultural landuse by using social survey data of farm equipment, figures on agricultural chemicals and farmers' behaviour; but such information might not be possible to obtain from remote sensing data. Likewise in social survey, maps are sometime used, but remote sensing data has greater spatial and temporal resolution. Besides, mapmakers usually select what is important to represent the theme of their studies. Nevertheless, remote sensing data might be used as a check on what is on maps and to provide useful alternative perspectives. In many occasions, it can also provide additional information which might not otherwise be in social survey maps.

The present study links the results of remote sensing with social survey, in order to assess the societal and environmental implications of landuse change in the Niger Delta. Questionnaire approach were used as quantitative means, while focus group discussion and interview were used as qualitative means of linking the results from remote sensing analysis with drivers of changes and their implications on the Delta.

3.5 Summary of the Chapter

The major synopsis from the above review is that Landsat data may help in the present study to examine the change in the Landuse in the Niger Delta of Nigeria. This is because Landsat data are cheap and have better multispectral resolution that is capable for regional landuse change study. Non-remote sensing methods appears to be a functioning complementary to remote sensing results to evaluate the drivers of landuse change and their societal implications. So this approach will be applied in the present study. DOS and histogram matching pre-processing methods will be utilised, because it is obvious from the review above that they perform better than other image atmospheric correction methods, especially when atmospheric and other environmental data are not available for simulation methods. Maximum Likelihood, post-classification and NDVI appear promising in landuse change detection. Though, the accuracy of some landuse change detection methods will be tested to select appropriate method to use in this study. The accuracy of landuse change results will be assessed using overall accuracy assessment method and Kappa statistics. Finally, the remote sensing findings will be complemented with qualitative and quantitative social survey methods to understand societal and health implications of results obtained from remote sensing analysis. What is revealing from the above review is that there is a potential for complementary application between remote sensing landuse change detection methods and social science methods. Hence, remote sensing will be used as to characterise landuse change, but the findings from remote sensing will be enhanced with qualitative social survey (interviews, focus groups, and questionnaires with local and regional stakeholders, residents, environmental organisations, agricultural and health practitioners). Detailed descriptions of the methods used in this study are discussed in next chapter.

CHAPTER FOUR
RESEARCH METHODOLOGY

This study used both quantitative and qualitative dataset to assess spatiotemporal landuse change in the Niger Delta. Quantitative data were acquired mainly from remote sensing while qualitative data were mainly derived from social survey and ancillary data. Table 4.1 presents the summary of the datasets used in the study and their coverage, while detailed description and information about Landsat data used in the study is presented in Table 4.2. The main objective of combining social survey data with remote sensing data is to examine the relationship between landuse change and the possible drivers of this change. The aim is to provide the evidence base to link the remote sensing results of change to its drivers. Thus, the next sections of this chapter present the remote sensing and non-remote sensing dataset and methods used to assess landuse change. The chapter is divided into two main sub-headings: The first sub-section discusses the remote sensing data acquisition and methodology, while the second section discusses social survey approach.

Table 4.1. The Summary of datasets used in this study.

Category	Data	Coverage	Use
Remote Sensing Data	Landsat Imagery	1987, 2001 and 2011. Five Landsat scenes were used in each year to cover the entire Niger Delta.	Image Classification and NDVI analysis for the entire Niger Delta.
	Landsat Imagery	1984, 1986, 1987, 1999, 2000, 2001, 2003, 2007 and 2011. At least six dates were used in each Landsat zone for case studies between 1984 and 2011	Image Classification and NDVI analysis for the specific case studies. Accuracy testing of classifiers was carried out using Landsat imagery acquired in 2011 for the western part of the Niger Delta.
	Landsat Imagery	January 19th 2007	To examine the potential of Landsat data in mapping the oil spill in Bomu.
	SPOT 5 image	2002 SPOT image for the entire Niger Delta,	for accuracy assessment of 2001 classified image.
Ancillary Data	Topo Map	The Niger Delta map sheets of 1985	Used for accuracy assessment of 1987 Image Classification.
	National forest report	The “State of Nigerian Forest” published by National Forest Department, Abuja 1985-2011	To determine the locations of forest reserves in the Niger Delta.
	Forest data from	The locations of forest and	To update The “State of

	Ramsar Convention and the World Database on Protected Areas (WDPA).	wetland in the Niger Delta, 2013	Nigerian Forest" published by National Forest Department, Abuja 1985-2011 and selection of case studies.
	GIS vector maps	The road network, settlements and drainage system.	To assess the roles of road network and settlement expansion on the rate of deforestation in the forest reserves in the Delta.
	GCPs Data	Ground control points (GCP) taken during the field work.	To rectify Landsat geometric distortions.
	Population data	Census data of 1991, 2006 and yearly household date from 1985 to 2011.	To assess the role of population increase in landuse change.
	Climatic data	Monthly rainfall and temperature for the period of 1980 to 2010 for the Niger Delta.	To assess the effects of climatic conditions in the Delta, on the accuracy of the classification maps and other landuse change detection analysis.
Social Data	Questionnaire,	250 questionnaires were administered in the major locations of suspected environmental change as seen on the results from remote sensing (see Figure 4.14).	To validate the findings from remote sensing results.
	Interview	One-to-one interview in 2011 and 213 to elicit different data from target population, Health professionals, a member of the Nigeria Conservation Foundation (NCF), the Director of the Institute of Ecology at the Obafemi Awolowo University, Ile-Ife, Nigeria and staff member of each of the forest reserves (see Figure 4.15).	To have insight into participants' understanding and their views about environmental changes around them and also to look at how such views differ by social groups.
	Focus group	Carried out in 2011 and 2913 to bring together for discussion, people who were known to have had certain experiences about the impacts of environmental changes in their communities.	To discover the perceptions of the local people of the social and health impacts of oil production activities on their communities.

Table 4.2. The information about Landsat Images used in the study, the path and the row with scene information of the Landsat used are presented in tabular form.

Applied for entire Niger Delta				**Applied for specific case studies**			
Images	***Acquisition Date. y-m-d***	***Path***	***Row***	***Images***	***Acquisition Date. y-m-d***	***Path***	***Row***
Landsat 4-5 TM 1987	1987-01-02	190	056	**Landsat 4-5 TM 1984**	1984-12-11	190	056
	1987-01-11	189	056		1984-12-13	188	056
	1987-12-21	189	057		1984-12-13	188	057
	1987-01-04	188	056				
	1987-01-04	188	057				
Landsat ETM + 2001	2001-02-17	190	056	**Landsat 4-5 TM 1986**	1986-12-19	188	056
	2001-01-09	189	056		1986-12-19	188	057
	2001-01-09	189	057				
	2000-12-17	188	056				
	2000-12-17	188	057				
Landsat ETM + 2011	2011-01-12	190	056	**Landsat 4-5 TM 1990**	1990-02-12	189	056
	2011-01-21	189	056	**Landsat 4-5 TM 1999**	1999-12-13	190	056
	2011-01-21	189	057	**Landsat ETM + 2000**	2000-12-17	188	056
					2000-12-17	188	057
	2011-12-16	188	056	**Landsat ETM + 2001**	2001-02-17	190	056
	2011-12-16	188	057	**Landsat ETM + 2002**	2002-01-28	189	056
				Landsat ETM + 2003	2003-01-08	188	056
					2003-12-10	188	056
				Landsat ETM + 2007	2007-01-01	190	056
					2007-01-19	188	056
					2007-12-28	189	056
				Landsat ETM + 2008	2008-02-14	189	056
				Landsat ETM + 2010	2010-12-11	190	056

4.1. Remote Sensing Methodology

To achieve remote sensing assessment of landuse change in the Delta, four essential steps were taken: (1) Dataset acquisition (remote sensing data and ancillary data), (2) Image pre-processing, which includes image calibration, geometric and atmospheric correction, (3) Change detection analysis, which includes classification and NDVI methods and (4) Post-classification assessment.

4.1.1. Dataset Acquisition

4.1.1.1 Remote Sensing Data Acquisition

Multi-date Landsat dataset between 1984 and 2011 were used in this research. A time series of Landsat satellite images were used, not only because Landsat data are useful for regional landuse study (such as the Niger Delta), but also because the data are freely available, since this research did not have sufficient fund to acquire higher resolution data. Moreover, Landsat provides bi-weekly data, useful for long-term multi-temporal landuse change detection (Kovalskyy and Roy 2013; Zhu and Woodcock 2014). Selection of long-time data was possible because the Landsat mission has long history, started in 1972, and it is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey (NASA 1979). Table 4.3 presents the detailed information about the spectral band characteristics and their applications. The Landsat images were collected from the archive of US Geological survey (through http://glovis.usgs.gov), consisting of TM (Landsat 5) and ETM+ (Landsat 7) sensors.

Table 4.3. Spectral band characteristics of Thematic Mapper (Source: NASA 2010).

Band Number	Spectral Resolution (µm)	Spatial Resolution	EM Region	Major Application Details
1	0.45-0.52	30 m	Visible-Blue	Coaster water mapping.
2	0.52-0.60	30 m	Visible- Green	Vegetation dynamic study.
3	0.63-0.69	30 m	Visible-Red	Chlorophyll absorption for vegetation differentiation.
4	0.76-0.90	30 m	Near Infrared (NIR)	Biomass survey.
5	1.55-1.75	30 m	Shortwave Infrared	Soil moisture, cloud and snow study.
6	10.4-12.5	120 m	Thermal Infrared	Thermal mapping.
7	2.08-2.35	30 m	Shortwave Infrared	Mineral mapping.

The Landsat data used in this study were acquired in January and December during the peak of the dry season of the Delta. Images are available for other months, but they cannot be used due to high cloud cover. Over 80 scenes were available for this region during dry season months; out of which only 45 scenes have cloud cover that is less than 2%, the threshold used in this study.

Five Landsat scenes are needed to cover the entire Niger Delta at a time, and these are called Landsat TM zones in this thesis (Figure 4.1). Green part of Figure 4.1 shows the location of the Niger Delta States, while different shadings represent the Landsat zones. One zone was used in a preliminary study for validation/accuracy assessment and covers the western part of the Delta. Multi-temporal datasets were used for spatial-temporal image analysis for the entire Niger Delta, while at least six dates were used in each Landsat zone between 1984 and 2011. Only three years of Landsat data could be used to assess landuse change for the entire Niger Delta, because they were the only years with Landsat images that had very low cloud cover for all the zones covering the Delta. These years were 1987, 2001 and 2011.

4.1.1.2. Ancillary Data Acquisition

Ancillary data was needed to provide additional data and increase the information available for separating the landuse classes, and for performing accuracy assessment. The Niger Delta map sheets from 1985 were collected from Nigerian National Petroleum Company (NNPC) office in Abuja. This map was one of the data used for accuracy assessment. Also, National report on the "State of Nigerian Forest" published by National Forest Department, Abuja were utilised to determine the locations of forest reserves in the Niger Delta. This information was further updated by the data on forest reserves in the Niger Delta collected from the archives of the Ramsar Convention and the World Database on Protected Areas (WDPA). GIS vector maps showing the road network, settlements, drainage system, were also used in the analysis. These vector data were collected from the database of International Food Policy Research Institute (IFPRI). These maps were updated with recent data that was collected during the field work. The vector of road network, settlement and data on forest reserves were used to assess the roles of road network and settlement expansion on the rate of deforestation in the forest reserves in the Delta.

In addition, population data were collected from National Population Commission (NPC), the main agency in charge of the population data for Nigeria. Census data of 1991 and 2006 were also collected. This data was used to assess the role of population increase in landuse change. Furthermore, climate data were collected from the archives of the Nigerian Meteorological Services, Oshodi Lagos, Nigeria. The climate data used in this study consists of monthly and annual rainfall total for the period of 1980 to 2010. Climate data were used to assess the effects of climatic conditions in the Delta, on the accuracy of the classification maps and other landuse change detection analysis.

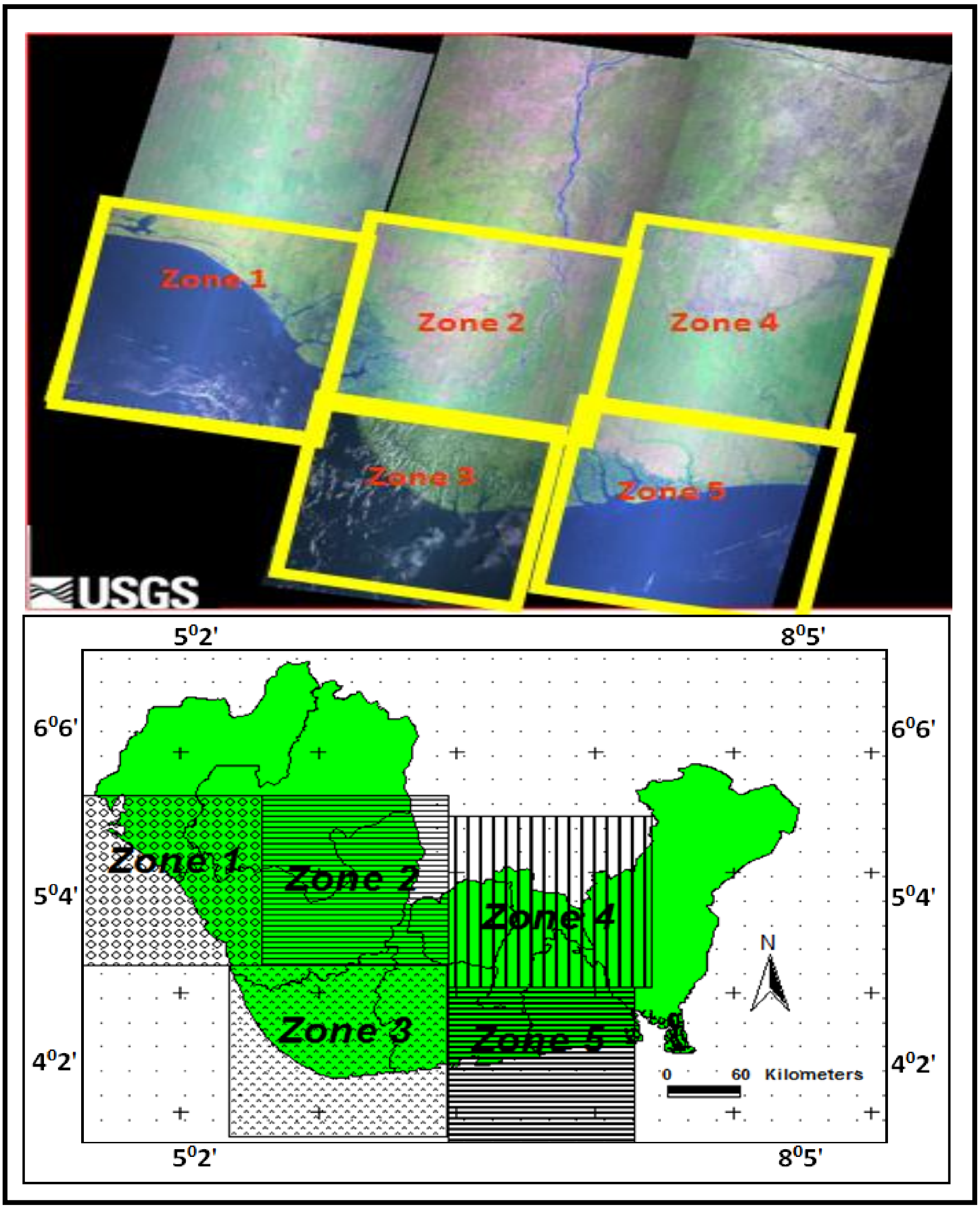


Figure 4.1. Map of the Niger Delta showing five Landsat scenes needed in the study

4.1.2. Image Pre-processing Methods

All the Landsat data used have been projected into Universal Transverse Mercator (UTM) map coordinates by NASA. Information about how Landsat images were georeferenced and evaluation of the results of the geometric correction using root mean square error, are presented in section 4.1.2.1. The images were later converted to Latitude-Longitude format for easy cartographic analysis. All overlay maps (e.g. state maps of Niger Delta, forest reserves and road maps), were also acquired and converted to Lat-Long.

4.1.2.1. Geometric Correction Procedure

In this study, spatial registration of the multi-date imageries is important because it is obvious from chapter three that spurious results of landuse change will be produced if there is a misregistration between multi-date images. This study used multi-date images from both Landsat TM and ETM+, and a slight variation in the geometry of the UTM correction was found. To rectify such geometric distortions, all the Landsat TM image data was registered to the 2011 ETM+ image. Each Landsat scene (zone) was geometrically corrected before they were mosaic together to assess landuse change in the entire Delta. The 2011 image had previously been georeferenced using the ground control points (GCPs) that were obtained during the field work. A total of 1870 GPS locations were taken during the field work (See Section 4.1.3.6), part of which were used for georeferencing. Geometric correction was achieved through referencing to carefully select between 17 and 21 GCPs in each of the different Landsat scenes, though, only 8 GCPs could be taken in zone 3 because of security issues during the field work. The GCPs were taken at the city centres of major urban areas, and at the centres of major forest reserves (Figure 4.2).

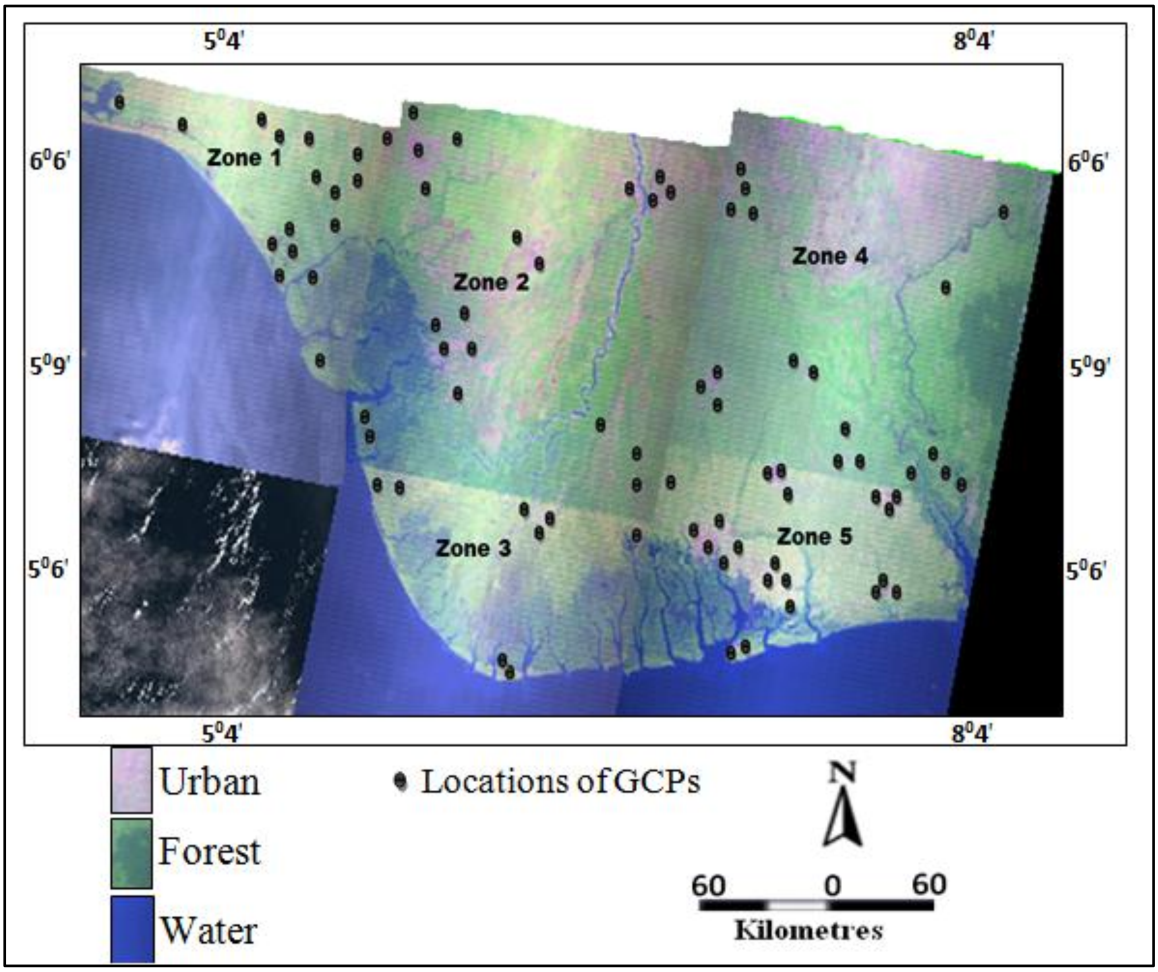


Figure 4.2. Distribution of GCPs used for georeferencing within the Niger Delta. Points on the maps show the locations of GCPs in relation to the Landsat zones

Table 4.4. Number of GCPS in different Landsat zones and total root-mean-square errors ($RMSE_{xy}$).

Landsat scenes	No. of GCPs	1987 Image $RMSE_{xy}$	2001 Image $RMSE_{xy}$	2011 Image $RMSE_{xy}$
Zone 1	17	$\pm$ 0.345	$\pm$ 0.261	$\pm$ 0.276
Zone 2	20	$\pm$ 0.596	$\pm$ 0.378	$\pm$ 0.398
Zone 3	8	$\pm$ 0.281	$\pm$ 0.178	$\pm$ 0.185
Zone 4	18	$\pm$ 0.341	$\pm$ 0.289	$\pm$ 0.295
Zone 5	21	$\pm$ 0.612	$\pm$ 0.453	$\pm$ 0.456

The affine transformation method was used to examine the root mean square (RMS) error. This method uses the coefficient derived from a set of control points for transforming the Landsat images. The RMS error was used to measure the precision of the control points in X and Y coordinates, i.e the deviation between the actual (true) and estimated (digital) location of the control points. This determines the errors between the source X and Y coordinates and the retransformed X, Y coordinates. Table 4.4 presents the $RMSE_{xy}$ for different Landsat zones using a set of check points for the different GCPS. What is clear from Table 4.4 is that RMS error values ($RMSE_{xy}$) for the control points increased as the number of GCPs increased. In zone 3 with 8 points for example, the $RMSE_{xy}$ is $\pm$ 0.281, but an increase of $\pm$ 0.612 was obtained for zone 5 where 21 points were used. Also, the $RMSE_{xy}$ varies from year to year, decreasing from year 1987 to 2011.

The above results are within the acceptable range, as suggested by previous studies (August *et.al* 1996 and Kardoulas *et.al* 1996). The studies have shown that a RMS error of < 1 is probably acceptable for Landsat scene with a ground resolution of 30 meters. Moreso, August *et.al* (1996) have earlier noted that although GPS can provide reliable and accurate geographic positioning for RMS error calculation, the accuracy of geometric correction depends on a number of control points (GCPs) used in the analysis. The results from the present study also show that the number of control points used contributed to accuracy and RMS error values (Table 4.4). The results presented in Table 4.4 also imply that increasing the number of GCPs has no significant implication in improving the geometric correction accuracy. Kardoulas *et.al* (1996) have also earlier noted that fewer points were needed to achieve better geometric correction accuracy. Thus, the study revealed that increasing the number of GCPS cannot greatly improve the geometric correction accuracy, because the GPS measurements in autonomous operation included errors which were not constant, either over time or for each GPS point.

The images were calibrated using Landsat calibration equation of ENVI "Band Math" for each date Landsat band (b_1 to b_7), as presented in Table 4.5. Detailed information about the fixed constants in the equations is available in the metadata of Landsat images used.

Table 4.5. Calibration equation used in ENVI band math to calibrate Landsat images

Landsat	Image Calibration Equations	
Landsat 5 (1984 to1998)	*Band 1*	$L_{\lambda} = (0.6794 * b_1) – 1.520$
	Band 2	$L_{\lambda} = (1.3222 * b_2) – 2.840$
	Band 3	$L_{\lambda} = (1.0440 * b_3) – 1.170$
	Band 4	$L_{\lambda} = (0.8760 * b_4) – 1.510$
	Band 5	$L_{\lambda} = (0.1204 * b_5) – 0.370$
	Band 7	$L_{\lambda} = (0.0655 * b_7) – 0.150$
Landsat 7 (1999 to 2011)	*Band 1*	$L_{\lambda} = (0.7787 * b_1) – 6.200$
	Band 2	$L_{\lambda} = (0.7988 * b_2) – 6.400$
	Band 3	$L_{\lambda} = (0.6217 * b_3) – 5.00$
	Band 4	$L_{\lambda} = (0.9693 * b_4) – 5.100$
	Band 5	$L_{\lambda} = (0.1222 * b_5) – 1.00$
	Band 7	$L_{\lambda} = (0.0439 * b_7) – 0.350$

4.1.2.2. Correction of Clouds, Shadows and Haze Effects on Image Data

As explained in section 4.1.1.1, though the images used in this study were cloud free, some cloud was noticeable over the ocean in one of the 2001 images. Clouds and their shadows were masked before performing classification. Cloud masking was performed by manual digitising using the region of interest (ROI) tool in ENVI. Furthermore, summary statistics for each scene and frequency histograms were performed for each band used (Section 4.1.3.2) in the analysis. As previously discussed in chapter two, the Niger Delta is near to Atlantic ocean with wet and dry season, implying high humidity, haze and many times poor visibility. The summary statistics of the image scenes, especially the frequency histogram for the bands, suggested further investigations of the need for atmospheric corrections.

Atmospheric correction was performed on all the images, since analysis of this research involves assessment of vegetation change using NDVI. Atmospheric correction is a critical pre-processing step because it has been shown in the literature that if atmospheric effects are not properly corrected, it can influence the NDVI results. From chapter three though, it is obvious that there is a divided opinion about necessity of atmospheric correction in landuse change detection analysis. Notwithstanding, the majority of these previous studies have noted that cl*oud* and other atmospheric conditions have significant influence on NDVI, indeed, most scholars believe that NDVI is unusable without atmospheric correction. For example, Agapiou *et al.* (2011) and Redowan and Kanan (2012) stated that slight changes in NDVI differencing values between two dates can occur as a result of different atmospheric conditions, with increased haze leading to a reduction in NDVI. Therefore the results from their studies showed that atmospheric correction is essential in NDVI analysis*;* thus, it is necessary to correct these effects prior the analysis.

Dark Object Subtraction (DOS) and histogram matching approaches were used to correct atmospheric effects. Water bodies were used as dark objects, because water has a very low radiance value compared to other objects in the images. DOS was calculated by subtracting the radiance value of the dark object in a band from every other value in that band. That is, signal value recorded over the water body was subtracted from the signal values of each pixel in the image.

After performing DOS, haze was evident in the 1987 Landsat images. Therefore, histogram matching was used to correct the hazy regions in the images. To perform this, a clear Landsat image of 2001 was displayed side by side with hazy images of 1987. Hazy regions were then corrected by matching the histogram of 1987 images with that of 2001 image.

4.1.2.3. Gap Filling of Images from 2003 to 2011

A primary limitation of using recent Landsat 7 ETM+ data for landuse analysis is that, due to the breakdown of scan-line corrector (SLC) since 2003, about 22% of data is lost, thus providing gaps in the imagery. It is important therefore, to implement techniques to fill-in the un-scanned gaps in the SLC-off data. Ever since the failure of Landsat 7 ETM+, studies have developed different approaches to fill the gap in the data. The most popular gap-filling methods in the literature are: Histogram matching (USGS 2004), the Object-based segmentation approach (Maxwell 2004; Maxwell *et al.* 2007), Neighbourhood Similar Pixel Interpolator (NSPI) (Chen *et al.* 2011) and Geostatistical Neighbourhood Similar Pixel Interpolator (GNSPI) (Zhu *et al.* 2012).

GNSPI were employed in the present study because it has been shown that it performs better than other methods. This might be because it uses geostatistical techniques, such as ordinary kriging and co-kriging interpolation techniques, to predict the missing value in a gap pixel (Pringle *et al.* 2009; Zhang *et al.* 2007; Zhu *et al.* 2012). For example, studies by Pringle *et al*. (2009) and Zhu *et al.* (2012) have shown that GNSPI can generate more accurate results than NSPI. Moreover, this approach can get accurate results for small and narrow landuse features, because it makes use of both spatial and temporal information. Images of the same year, but of different dates were used for gap filling of the Landsat data from 2003 to 2011, which are summarised in Table 4.6. In this study, gap filling was achieved for 2011 image for the entire Niger Delta, while in some specific case studies, 2003; 2007; and 2008 images were filled with images of the same area from other dates. The reason for doing this is that the missing data resulting from the SLC anomaly, could be replaced by data in the subsequent passes over the same scene, with the result that every location would be observed eventually (USGS 2003; 2004). From Table 4.6, gap filling for all the images was based on a subsequent pass over the same scene, except for images acquired on February 14 2008 and January 12 2011, when the gaps were filled by previous pass over the same scene on December 28 2007, and December 11 2010 respectively. Figures 4.3A, B, C and D show that the results of gap filling using the example of images of Irele community. Figure 4.3A is a 2011 colour composite image with gaps; 4.3B is the filled image; 4.3C is the result from classification of filled image, while 4.3D is an example of the results after gap filling. The location marked with a white circle is the point with a persistent gap before GNSPI was improved. The major limitation observed when applying this method was that some minor gaps were still persistent at the edge of the classified image (Figure 4.3). These minor edge problems were rectified by applying GNSPI.

Table 4.6. Landsat ETM+ images used in gap filling

	Original Images			Image Used for Gap Filling			
Images	**Acquisition Date. y-m-d**	**Path**	**Row**	**Acquisition Date. y-m-d**	**Path**	**Row**	**Application in this Study**
Landsat ETM + 2003	2003-01-08	188	056	2003-12-10	188	056	Applied for specific case studies
Landsat ETM + 2007	2007-01-17	190	056	2007-01-01	190	056	
	2007-01-03	188	056	2007-01-19	188	056	
Landsat ETM + 2008	2008-02-14	189	056	2007-12-28	189	056	
Landsat ETM + 2011	2011-01-12	190	056	2010-12-11	190	056	Applied for entire Niger Delta
	2011-01-21	189	056	2011-01-05	189	056	
	2011-01-21	189	057	2011-01-05	189	056	
	2011-12-16	188	056	2011-11-30	188	056	
	2011-12-16	188	057	2011-11-30	188	057	

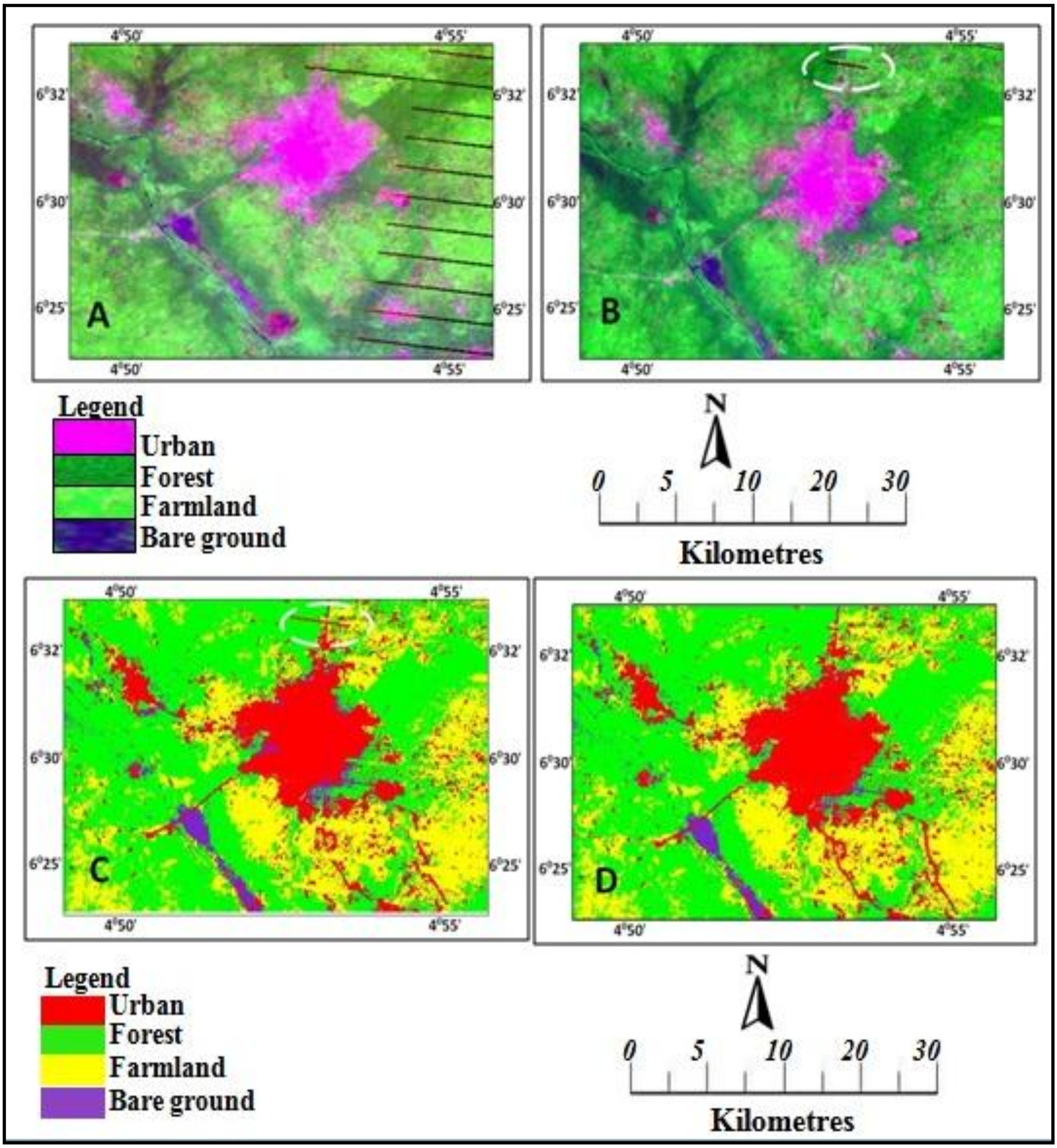


Figure 4.3. Results of gap filling in Irele community

4.1.3. Landuse Change Detection Method: Classification

Supervised classification and post-classification change detection methods were used to examine landuse change (LUC) in the Niger Delta. Image classification was carried out following these steps: (1) Selection of training site (2) Selection of classes and tests of their separability (3) Selection of classification method (4) Field data collection for classification accuracy assessment (5) Accuracy assessment (6) Post-classification analysis and assessment of intra-annual rate of landuse change (7) Landuse change map production.

4.1.3.1. Selection of Training Pixels for Classification

Training sets for each class were established using Google earth image data. Training sites were selected from areas with relatively uniform appearance on the image and then using the region of interest (ROI) tools in ENVI to define them. A total of 45 ROIs were used for training each Landsat scene. It has been earlier reported in the literature that accurate selection of training data is as important as the choice of classification algorithm or landuse change detection methods (Campbell 2006, Aplin 2005, Morton *et al.* 2011).

The size of training data is important, so each was large enough to provide adequate information. The training areas were positioned with features which could be easily recognised on Google earth images. Thus, by using the training dataset and ROI, every pixel in the image was classified into one of the desired classes. Another important issue considered properly in the selection of training areas, is their uniformity, which interpretation of Google Earth imagery was used to evaluate. When doing this, the spectral properties of each landuse class were located within uniform areas and a block of contiguous pixels were used.

4.1.3.2. Method of Class Selection and their Separability

Selection of classes and their separability were tested using Transformed Divergence (TD) which was based on the 2011 image for the western part of the Delta (Zone 1 in Figure 4.1). This method of separability analysis is a statistical means of evaluating whether a pair of classes is separated or not. Various ways of measuring class separability are discussed in the literature; popular methods are Bhattacharyya distance, Jeffries-Matusita (JM) distance, and transformed divergence (TD). It has been reported that TD is the most appropriate algorithm for maximum likelihood classification and post-classification (Swain and Davis1978; Morton *et al* 2011). TD methods were carried out in this study for two major purposes: (1) to select appropriate landuse classes from proposed landuse classes in the previous studies (2) to assess how separable the selected classes are, since good classes separability produces better landuse classification results, and (3) TD was used also to select the best band combination, on which training data and site were applied for ML classification.

TD values were calculated to indicate the separability between classes using the following formula (Swain and Davis, 1978):

$$TD_{ij} = 2[1 - \exp(-D_{ij}/8)] \qquad (4.1)$$

Where TD_{ij} is the transformed divergence; D_{ij} the divergence measure; and i and j are the two signatures (classes) being compared. The TD value increases as the distance between classes increases. D_{ij} can be computed from the following formula (Swain and Davis, 1978):

$$D_{ij} = \frac{1}{2}\mathrm{tr}\left[(V_i - V_j)(V_i^{-1} - V_j^{-1})\right] + \frac{1}{2}\mathrm{tr}\left[(M_i - M_j)(M_i - M_j)^T(V_i^{-1} - V_j^{-1})\right] \qquad (4.2)$$

Where i and j are the two signatures (classes) being compared, V_i represents the covariance matrix of signature I, M is the mean vector of signature i, tr represents the trace function, and T is the transposition function.

Generally, TD separability values range from 0 to 2.0, but studies have reported that values greater than 1.7 indicate that the classes have a good separability. To minimize error that might occur due to seasonality or phenology effects, three images (1987, 2001 and 2011) acquired during the same season, between December and January, were selected and used, and the results of statistical separability are presented in tables below. Table 4.7 shows the TD values for different eight classes based on the Niger Delta Environmental Survey, NDES (NDES, 1997), using the 2011 image. The NDES classification systems consisted of seven classes comprising of: Urban areas, Cultivated land, Natural forest, Palm plantation, Water, Mangrove (short) and Mangrove (tall) (NDES, 1997).

Table 4.7. Transformed Divergence Values for eight classes.

Classes	Urban Area	Cultivated Land	Bare Ground	Natural Forest	Palm Plantation	Water	Mangrove (Short)	Mangrove (Tall)
Urban area		1.960	1.635	1.911	1.954	1.978	1.904	1.692
Cultivated land	1.960		1.996	1.404	1.768	2.000	1.719	1.951
Bare ground	1.635	1.996		1.984	1.955	2.000	1.964	1.998
Natural forest	1.911	1.404	1.984		0.804	2.000	0.920	1.589
Palm plantation	1.954	1.768	1.955	0.804		2.000	0.605	1.832
Water	1.978	2.000	2.000	2.000	2.000		2.000	1.755
Mangrove (short)	1.904	1.719	1.964	0.920	0.605	2.000		1.648
Mangrove (tall)	1.692	1.951	1.998	1.589	1.832	1.755	1.648	
Average	1.862	1.828	1.933	1.516	1.56	1.962	1.537	1.781

It is clear from Table 4.7 that palm plantation class has poor separability with natural forest (TD = 0.80), and mangrove short (TD = 0.61). The reason for their poor separability might be due to the fact that majority of oil palm trees in the plantation are matured trees and they have a similar signature as forest and mangrove. Consequently, Landsat could not separate the area covered by palm plantation from that of forest vegetation. Mangrove short not only has poor separability with natural forest with TD values of 0.92, but both mangrove short and tall also have poor separability (TD = 1.64). It is also clear from Table 4.7 that out of all eight classes, only five classes are separable with average TD values greater than 1.70. The classes are urban (TD = 1.86), cultivated land (TD = 1.83), bare ground (1.93), water (TD = 1.96) and Mangrove tall (1.78).

Though both mangrove short and natural forest have poor separability, they are important vegetation classes in the Delta (Chapter two). To improve TD values and to also select appropriate landuse classes for this research, both short and tall mangroves were combined as a single mangrove class. Likewise, both cultivated land and palm plantations were combined to form one major class called farmland. Therefore, six classes with separability greater than 1.70 were selected from the NDES classification system: Urban, Cultivated land, Bare ground, Natural forest and Water (Table 4.7). The names of the new classes were also modified to have more explanatory descriptions of the combined classes: Natural forest is now named Forest; both mangrove short and mangrove tall are now Mangrove; cultivated land and plantation are now Farmland; while Water, Urban and Bare ground retain their names.

Separability analysis was carried out on the six classes to test their class signature and separability, and the results are presented in Tables 4.8 and 4.9. What is obvious from these results is that forest has poor separability with farmland (TD =1.62), and mangrove (TD=1.65), but all other classes have TD values above 1.70.

In order to see if the separability problems between forest and farmland; and forest and mangrove; were due to the number of bands used in the classification class, separability was investigated for different band combinations (Table 4.10). Five series of possible band combinations for Landsat were investigated. It was found out that the water class is always very much separable from other classes with TD above 1.90 in all bands combinations. In the six bands dataset, it is clear that bare ground has low separability with urban and farmland classes, with TD values below 1.60. Likewise in these series, there is no clear distinction between forest and farmland; mangrove and forest classes with TD values of 1.576 and 1.583 respectively (Table 4.10). The results of five band combination indicate higher transformed divergence values for the urban class, which show that it is highly separable from other classes in the combination series. Low TD values were obtained for mangrove and forest with TD=1.599; and forest and farmland with TD = 1.583. Generally, in all bands combination, there appeared to be very low separability between forest, mangrove and farmland; with TD values below 1.60, except in three bands combination where their values are above 1.60.

Table 4.8. Transformed Divergence Values for the different six classes

Classes	**Urban**	**Farmland**	**Bare Ground**	**Forest**	**Water**	**Mangrove**
Urban		1.984	1.883	1.945	1.994	1.818
Farmland	1.984		1.998	1.624	2.00	1.978
Bare ground	1.883	1.998		1.995	2.00	2.00
Forest	1.945	1.624	1.995		2.00	1.653
Water	1.994	2.00	2.00	2.00		1.848
Mangrove	1.818	1.978	2.00	1.653	1.848	
Average	1.925	1.917	1.975	1.843	1.968	1.859

Table 4.9. Landuse classification system for Niger Delta.

Class	Land Use/Land Cover	Description
1	Urban	Built-up land for residential, commercial services, industrial, transportation, communications, industrial and commercial, mixed urban and rural build-up land.
2	Farmland	Agricultural farmland, crop fields, pasture, and bare fields within farmland.
3	Water	Permanent open water, lakes, reservoirs, streams, estuaries and ocean.
4	Mangrove	Red mangrove, white mangrove, brackish swamp forests and beach forest.
5	Forest	Lowland rainforest, freshwater mangrove, forest reserves and protected areas.
6	Bare ground	Open lands without vegetal cover.

TD values for three bands combination show high separability for all classes. All TD values are above 1.90 which illustrates a clear distinction between classes. Thus, since the three bands combination (bands 3 4 7) produces the highest TD values, this combination was used for all separability analysis and for image band combination during colour composite analysis.

Table 4.10. Transformed divergence values of landuse classes from possible band combination. A = six bands (123457), B= five bands (13457), C= four bands (1347), D= three bands (347) and E= two bands (34) combinations.

	Class names	Urban	Farmland	Bare ground	Forest	Water	Mangrove	Average
A	**Urban**	0						
	Farmland	1.987	0					
	Bare ground	1.583	1.542	0				
	Forest	1.945	1.576	1.947	0			
	Water	2.000	2.000	1.995	1.995	0		
	Mangrove	1.990	1.675	1.624	1.583	1.748	0	1.813
B	**Urban**	0						
	Farmland	1.945	0					
	Bare ground	1.649	1.988	0				
	Forest	1.945	1.583	1.967	0			
	Water	1.994	2.000	2.000	1.997	0		
	Mangrove	1.988	1.878	1.868	1.599	1.787	0	1.878
C	**Urban**	0						
	Farmland	1.978	0					
	Bare ground	1.673	1.996	0				
	Forest	1.945	1.594	1.995	0			
	Water	1.984	1.998	2.000	1.995	0		
	Mangrove	1.818	1.965	1.945	1.643	1.848	0	1.892
D	**Urban**	0						
	Farmland	1.984	0					
	Bare ground	1.957	1.998	0				
	Forest	1.945	1.863	1.995	0			
	Water	1.994	2.000	2.000	2.000	0		
	Mangrove	1.934	1.978	2,000	1.876	1.961	0	1.965
E	**Urban**	0						
	Farmland	1.923	0					
	Bare ground	1.682	1.945	0				
	Forest	1.899	1.543	1.978	0			
	Water	1.998	1.965	1.876	1.968	0		
	Mangrove	1.891	1.978	1.973	1.564	1.984	0	1.878

4.1.3.3. Selection of Classification Method

At the start of the classification analysis, six classification methods were tested and their accuracy assessed: Parallelepiped (PL); Minimum Distance (MD); Mahalanobis Distance (MHD); Spectral Angle Mapper (SAM); Maximum Likelihood (ML) and Support Vector Machine (SVM) methods. Accuracy testing of these classifiers was carried out using Landsat imagery acquired in 2011 for the western part of the Niger Delta (Zone 1). Reference data used to perform this assessment were those collected during the field work (See Section 4.1.3.4). Accuracy assessment of different classifiers was evaluated to select the most accurate classification method for the environmental issues in the Niger Delta. Several approaches have been used in the literature to assess accuracy of landuse classification, but in general, scholars perform accuracy assessment by comparing the classification results with some other reference data. Such reference data include: Higher resolution satellite images; aerial photo interpretation and data from ground truthing or field observation. The present study used ground truth data to perform accuracy assessment of different classifiers. This approach was carried out, not only because several studies have shown that it performs better than other methods, but also due to the fact that recent higher resolution satellite images for use in accuracy assessment are expensive and no recent aerial photo exists for the region of this study.

4.1.3.4. Field Data for Classification Accuracy Assessment

The field data were collected to generate reference data to assess the accuracy of the classification images. Field work was carried out in two stages. The first field visit was conducted after preliminary study, during the dry season of 2011 (three months), while a two month post-analysis field study was carried out in dry season of 2013. This research was guided by a Global Positioning System (GPS). Four sets of Garmin GPSs (Three Garmin 72H GPS and a Garmin 12XL GPS) were used in the field to locate sample points and record the coordinates of all sample points. The details of how sample points were selected are presented in Sections 4.1.3.5 and 4.1.3.6.

4.1.3.5. Field Sampling Scheme Used for Remote Sensing Classification Maps

The study used a stratified random sampling technique to collect data during field work, because the method accounts for both small and large classes in sample selection and it is the method that is the most representative of all classes in image classification maps**.** Besides, since the stratified random method is probabilistic, it allows us to make statistical conclusions from the sampling data collected. Sampling techniques available in ENVI were used to generate a stratified random sampling of points from a classification map.

There are two ways to perform stratified random sampling in ENVI: Proportionate and Disproportionate. For this research, the proportionate approach was used because it produces sample sizes that are directly related to the size of the classes, and improves the potential for the sample points to be more evenly distributed over the sampling area (Glenn 2010). This approach was used in all sampling areas visited: Okitipupa and Irele areas; Okomu forest reserve and national park; Port Harcourt, Tsekelewu, Eket and Oboolo (Figure 4). These locations represent the different classes of the study area, though we could not take samples in the Southern part of the Niger Delta due to security issues.

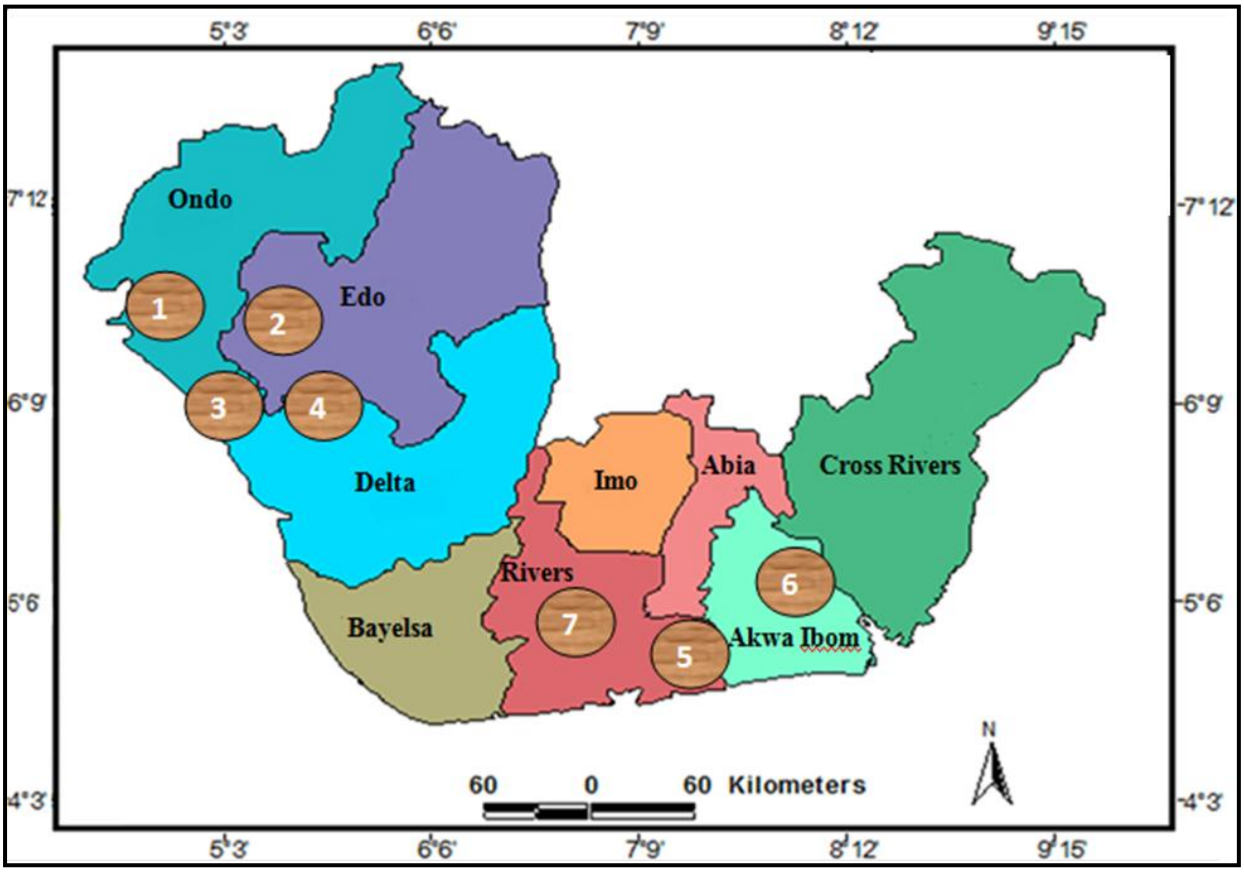


Figure 4.4. Location of sample areas visited during field work: 1. Okitipupa/Irele 2.Okomu 3. Tsekelewu 4. Gilli-Gilli 5. Oboolo 6. Eket and 7. Port Harcourt

4.1.3.6. Implementation of Sampling Scheme

Classification maps were converted to regions of interest (ROIs) for each location, where samplings were undertaken (Figure 4.5). Each ROI map was further divided into eighteen homogeneous polygons (Pg). In each Pg, ten simple points were taken randomly (Figure 4.6). At least 100 sample points were taken in each location (Figure 4.5). Thus, the total sample points (870) collected in entire Niger Delta correspond to 180 sample points in Okitipupa and Irele areas; 180 in Okomu forest reserve and national park; 130 in Port Harcourt, 180 in Tsekelewu, 100 in Eket and 100 in Oboolo (Appendix I). Less than 180 samples were taken in Port Harcourt, Eket and Oboolo due to communal conflicts in the area, which limit accessibility to some areas.

About fifty five of these ROI maps at 1:10,000 scales were printed. These were used for navigation purposes in order to verify landuse changes and other environmental degradation features at the specified locations. The landuse on the ground was recorded on a field note as illustrated in Table 4.11. Also, photographs of different sites were taken, while details of the landuse as observed in the field were noted and recorded using field notebook (Table 4.11).

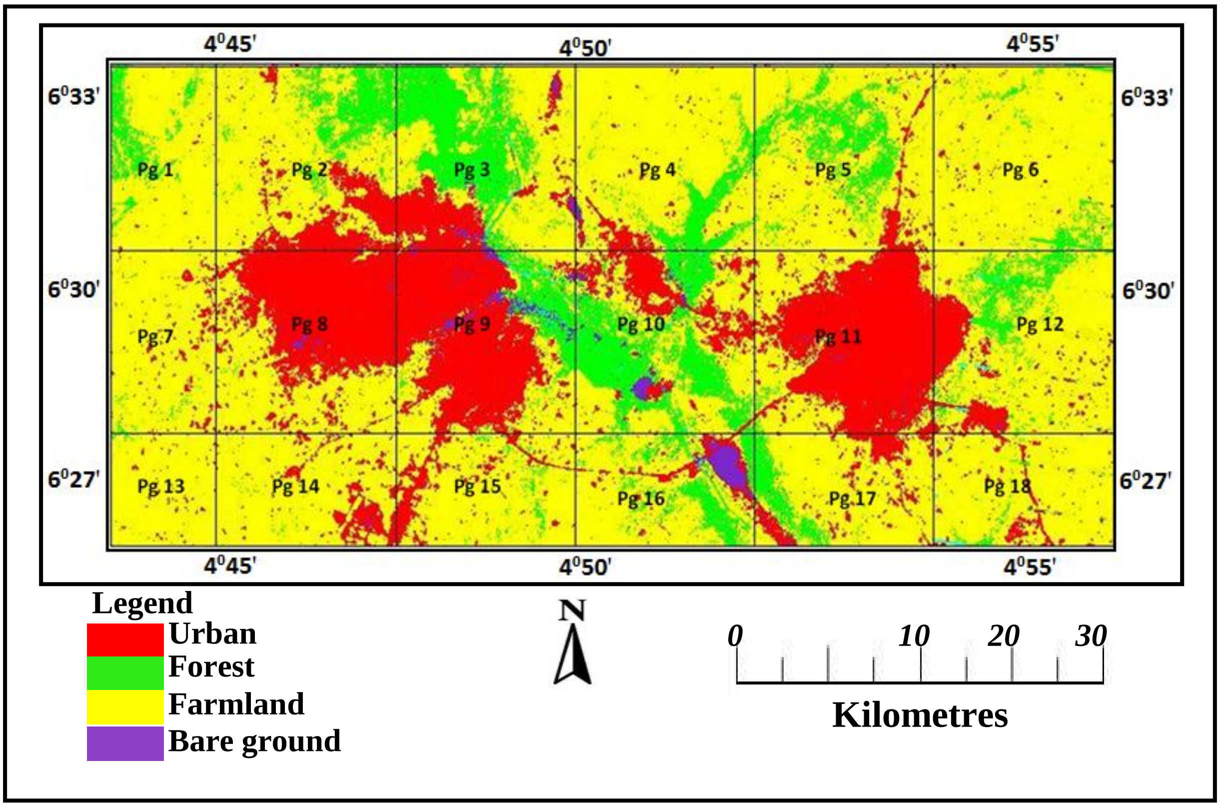


Figure 4.5. Example of a sampling area polygon near Okitipupa. Pgs 1 to 18 are the sampling area polygons, where ten sampling points (at least) were taken.

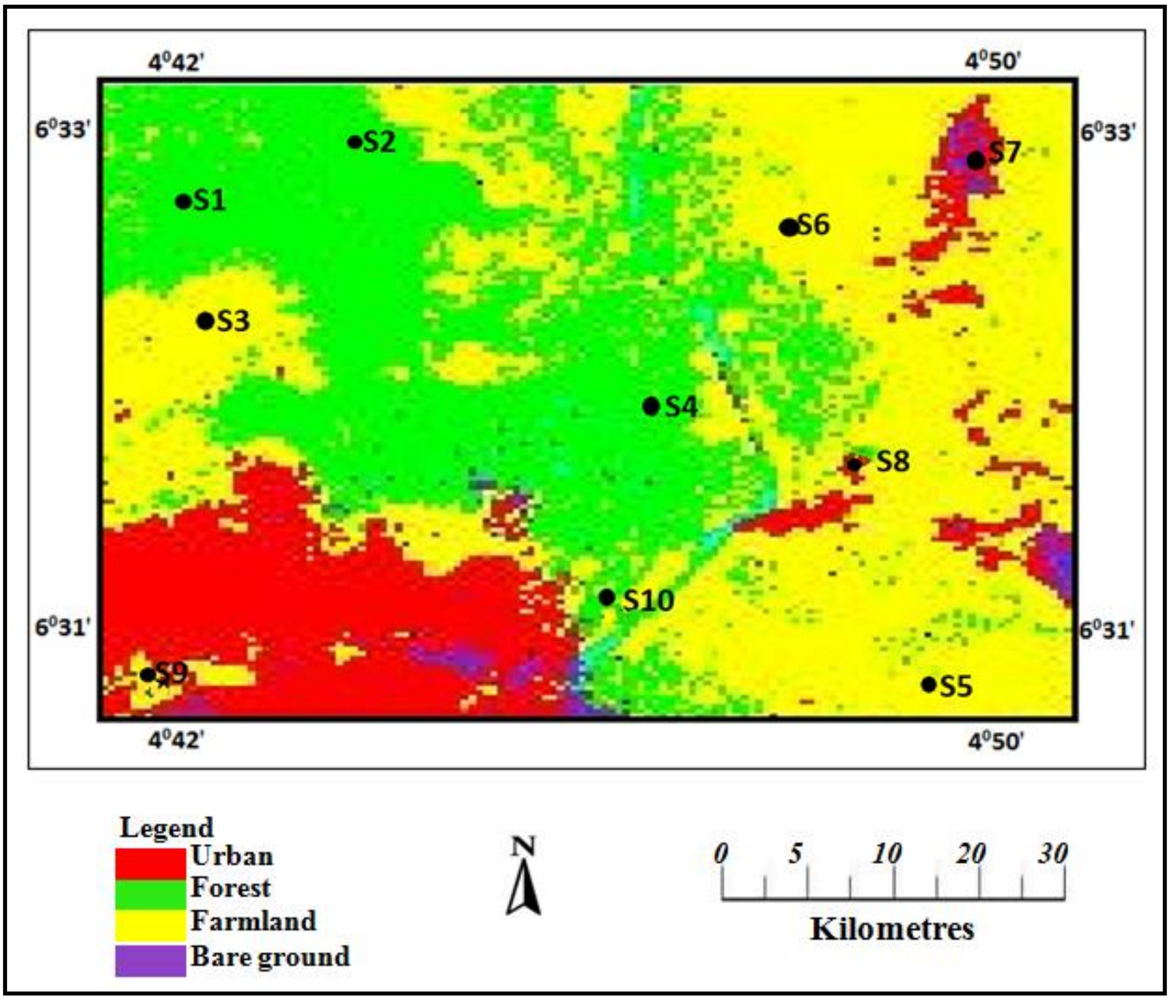


Figure 4.6. Example of ten field sampling and observation points in Pg 3 of Figure 4.4 around Okitipupa. S1 to S10 are the observation points.

Table 4.11. Example of field notes taken during field work in Ajagba area

Landuse survey (Western part of the Niger Delta of Nigeria) **Field Note**		
Location: Ajagba (Irele)	Lat **$06^{0}.25.54^{1}$**	Long **$004^{0}.55.40^{1}$**
Polygon ID: PG 12		
Date: 2/11/2011		
Surveyor	Wola	

Sample Point ID Lat Long	***Landuse***	***Remark***
S1 **$06^{0}.26.36^{1}$ $004^{0}.58.20^{1}$**	Farmland	Cultivation Land
S2 **$06^{0}.29.24^{1}$ $004^{0}.52.13^{1}$**	Urban	Commercial and residential
S3 **$06^{0}.28.34^{1}$ $004^{0}.53.80^{1}$**	Mangrove	Swamp (*trees with some scatter mangrove)*
S4 **$06^{0}.25.08^{1}$ $004^{0}.58.21^{1}$**	Farmland	Cultivation within forest
S5 **$06^{0}.28.78^{1}$ $004^{0}.53.80^{1}$**	Forest	Forest with *Scrub and palm*
S6 **$06^{0}.25.05^{1}$ $004^{0}.55.80^{1}$**	Urban	Rural settlement
S7 **$06^{0}.26.01^{1}$ $004^{0}.54.66^{1}$**	Farmland	Cultivated land / plantation
S8		
S9		
S10 **$06^{0}.29.56^{1}$ $004^{0}.53.43^{1}$**	Forest	Traditional forest

Major Landuse	**Possible Classes**
Urban	*Rural settlement* *Residential Urban* *Commercial Urban*
Farmland	*Cultivation Land* *Plantation: Oil palm; Rubber e.t.c (specify)* *Cultivation land within Forest* *Cultivation and palm* *Other*
Forest	*Forest reserves* *Secondary growth* *Saltwater impacted forest* *Palm Forest* *Scrub* *Scrub and palm* *Other*
Mangrove	*Short or tall mangrove dominated* *Submerged mangrove* *Marsh(low growing plants/grass with water)* *Swamp(trees with some scatter mangrove)* *Raffia palm complex* *Other*
Water	*Rivers / streams / creeks / Lagoons* *Ponds / Lakes* *Dredge canals* *Pipeline row with water* *Other*
Bare Ground	*Open bare surface* *Sand beach* *River course sandy areas* *Tidal flats* *Dredge spoil* *Open hills* *Other*

4.1.3.7. Preparation and Execution of the Field Work

Four field assistants were hired for the field exercise. Two of them were Postgraduate (masters) students and two were undergraduate students of Obafemi Awolowo University (OAU), Ile-Ife, Nigeria. Also, in each sample area, two local people from nearby villages were hired to assist as guides around the sample areas. Thus, a total of 16 assistants were hired; 4 students from OAU, and 12 local people from sample areas (2 people from each of the 6 sample areas).

The majority of sampling points visited were off the major roads and there were no existing maps showing the minor roads and footpaths. Thus, route planning was conducted for the first two days in each location. The plan also involves how to get to towns or villages close to a sample area for focus group discussion and questionnaire administration (See Section 4.2.2). Reconnaissance surveys were carried out to interact with the leaders of communities and managers of forest reserves (as the case may be), in the sampling areas. This was necessary to obtain permissions and support for the field exercise in their communities. Details of field work preparation, planning and implementation are presented in Appendix K.

4.1.3.8. Accuracy assessment

Three sets of reference data were used (Table 4.12). 1985 Topographic (Topo) maps of the Niger Delta were used to assess the accuracy of 1987 classification image; a 2002 SPOT image was used to assess the accuracy of 2001 classification image; while ground truth data collected during field work were used to perform accuracy assessment of 2011 classification image. A total of 160 sample sites were randomly allocated on Topo maps and SPOT image while ground truth data were based on field survey that was described in the previous section. The Topo maps show both natural and human features; these are urban, water, farmland, forest, mangrove and road. All the classes are shown on the Topo map except bare ground. Consequently the accuracy classes that were on the maps were determined, and the ones that were not, was ignored.

The SPOT 5 image was interpreted for class information that was used for accuracy assessment of 2001 classified image. SPOT 5 has a resolution of 10 meters in red, green and NIR bands, but 2.5 meters in panchromatic mode. Bands in Green (0.5-0.59 μm), Red (0.61-0.68 μm) and NIR (0.78-0.89 μm) were used to perform colour combinations. The sample points from Topo maps and SPOT images (Figure 4.7) were compared with classification image of 1987 and 2001 respectively, and this was used to develop confusion matrices. Accuracy assessment were carried out by generating conventional confusion matrices, which compares the class labels of pixels within a 5 x 5 pixel window centred on each site. Landuse class statistics generated in this way were compared with reference data and summarized in a confusion matrix (also known as error matrix). A confusion matrix was used in this study, not only because it identifies errors of classification images, but also as it identifies misclassification of landuse classes.

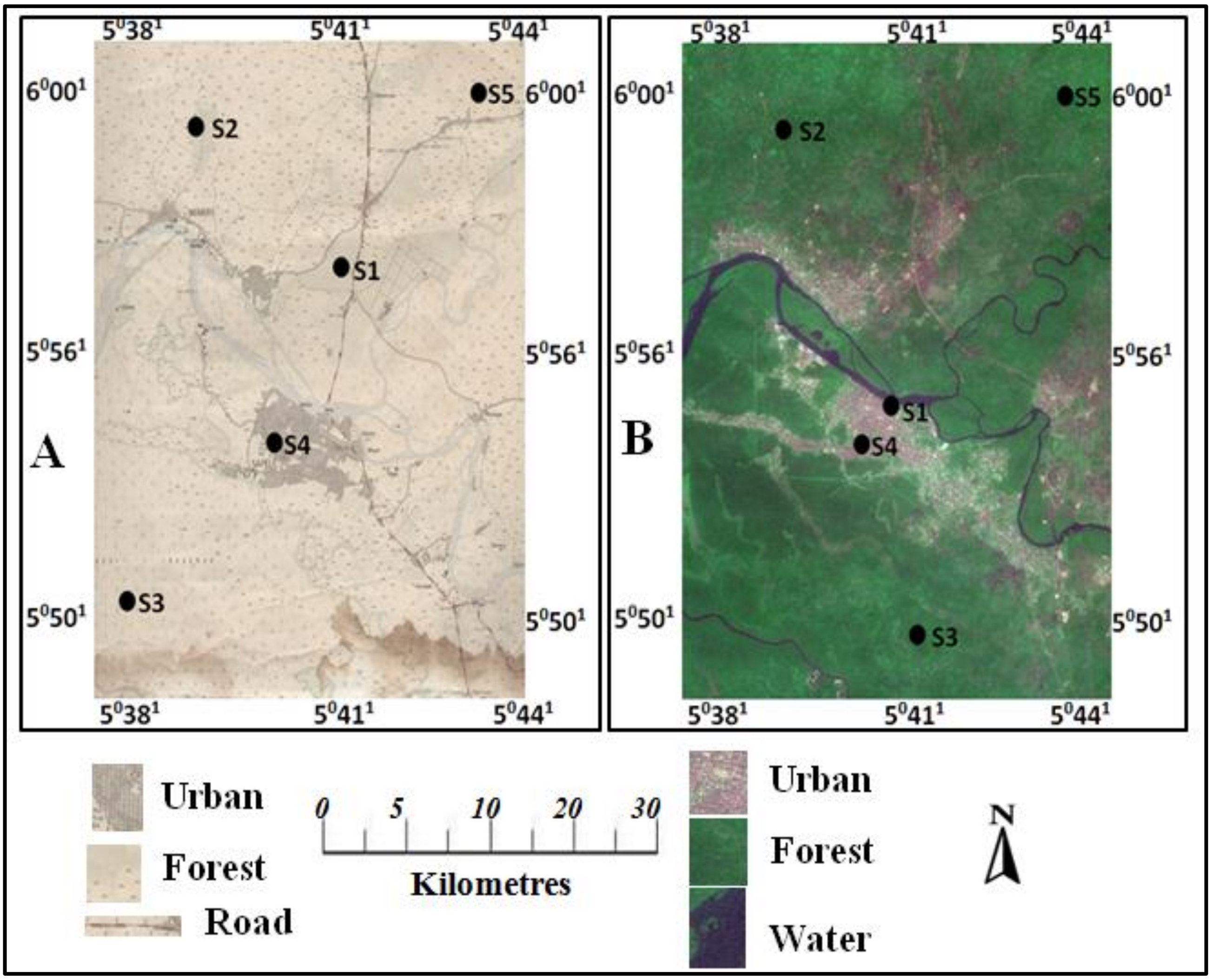


Figure 4.7. Example of sampling area polygon from the topo map (A) and the Spot 5 image (B). The location is the region around Okitipupa. S1 to S5 are the observation points.

The image classification accuracy was further assessed by calculating the overall accuracy and kappa coefficient. The overall accuracy was calculated by dividing the major diagonal (the number of correct classes based on observation and classification results) by the total area in percentage (Eq 4.3).

$$\text{Overall accuracy} = \left(\sum^{\text{i=landuse classes}} \text{Ci} \right) \Big/ \text{C++} \quad *100 \qquad (4.3)$$

Where C_i is the major diagonal for all corrected classes, and $C{+}{+}$ is the total number of accuracy sites. It should be noted that the major diagonals represent sites which were classified correctly according to ground truth data obtained during the field visit. Thus, off-diagonals signify misclassified categories.

In addition, the kappa statistic tests were calculated to show differences between actual agreement and the agreement expected by chance between classification maps and ground truth observation (Ellis and Porter-Bolland, 2008). The method is expressed in equation 4.4 below:

$$\widehat{\mathrm{K}} = \frac{\mathrm{N} \sum_{i=1}^{r} \mathrm{X_{ii}} - \sum_{i\text{-}1}^{r} (\mathrm{X_{i+}} \times \mathrm{X_{+i}})}{\mathrm{N}^2 - \sum^{r} (\mathrm{X_{i+}} \times \mathrm{X_{+i}})} \qquad (4.4)$$

Where r is the number of rows in the confusion (error) matrix, x_{ii} is the number of observations in row i and column i (on the major diagonal), x_{i+} is the total observations in row i, x_{+i} is the total observations in column i, and N is the total number of observations included in the matrix. Though, limitations of this method are well documented in the literature. For example, Janssen and Van-Derwel (1994), Almutairi and Warner (2010), Aguirre-Gutiérrez et al. (2012) and Stehman (2012) have revealed that Kappa statistic is affected by the size of sample population of reference data under consideration, and the number of classification categories in remote sensing analysis. Despite this problem, none of other approaches of assessing the accuracy of classification maps, as reviewed in chapter three, provides opportunities to measure differences between the observed agreement between two maps and the agreement that might be attained solely by chance, just like Foody (2002) and Campbell (2006) reviewed different classification accuracy assessment methods and discussed some issues relating to the effectiveness of each accuracy assessment method. Therefore, other commonly used methods of classification accuracy assessment solely measure what proportion of the classification decision that is correct (Campbell 2006) and thus in the present study, Kappa statistic tests were used in combination with the other methods.

4.1.3.9. Comparing the Accuracy of Different Classifiers

Selection of the classifier used in this study was based on the results of accuracy assessment of all the classifiers studied (i.e. PL, MD, MHD, SAM, SVM and ML) as presented in Table 4.12. As SVM takes weeks to run on an entire Landsat TM image, it was tested on a small part of the 2011 Zone 1 Landsat ETM image data (the Okitipupa area), to assess accuracy of the method. ML classification was also run on this region for comparison purposes, while the rest of the classifiers were tested on the entire image.

Table 4.12. Accuracy of the different classifiers tested

	PL	MD	ML	SAM	MHD	SVM *	ML *
Overall accuracy (%)	28.0	47.4	71.6	57.6	61.4	79.6	76.8
Kappa (%)	10.0	34.3	67.4	46.6	51.3	61.8	68.4

* *Accuracy for small part of Okitipupa*

The accuracy of Maximum Likelihood (ML) and Support Vector Machine (SVM) appear much better than the other classifiers. Overall accuracy and Kappa for parallelepiped classification (PL) were very low as shown in Table 4.10, which shows that MD, ML, SAM and MHD are more accurate. Though, out of these three classifiers, ML is the most accurate, while MD is much worse. The Kappa value of ML was much better than other classifiers (Table 4.12). These values suggest that ML was the most accurate method, thus, it was employed to classify the rest of the Delta. A further reason for making this decision was that the time taken to classify an image for ML is much faster than that of SVM. For example, ML took few minutes to classify the images for the whole Niger Delta, but, SVM took one week to perform it for a small area.

There have been diverse opinions about the performance of both ML and SVM in the literature. Some studies observed that SVM performs better than other classifiers (Huang et al, 2002), while other studies have shown that SVM performances depend on the ecology of the study area, dataset used and equality of training samples selected (Foody and Mathur 2004; Otukei and Blaschke 2010). But, all studies agree that SVM is very slow in operation.

4.1.3.10. Maximum Likelihood Classification

Out of all classifiers tested, only Maximum Likelihood (ML) is found most useful to assess landuse change in the Niger Delta of Nigeria, based on the results of accuracy assessment in Section 4.1.3.9. Thus, the image classifications for all images were carried out using ML.

4.1.3.11. Uncertainties in Maximum Likelihood Classification

Despite high separability values obtained for almost all the classes, (apart from forest and mangrove), the ML classification analysis showed large scale switches between different classes for the multi-date images, many of which were unrealistic and erroneous. It is clear from confusion matrices that the majority of misclassification was between forest and mangrove; and bare ground and urban classes (Tables 4.13, 4.14 and 4.15). Misclassification between forest and mangrove is expected, since their separability was very low from TD analysis in Section 4.1.3.2. In some areas, urban changed to bare ground and back again to urban (a landuse change that is unlikely to be very common), while in other urban regions, there were persistent occurrences of bare ground. The ML classified maps have the tendency of overestimating the bare ground class, and appeared to include a lot of bare ground within urban areas. These are probably errors, as many bare areas would not be expected to fall within urban areas; and switch between urban and bare ground; and back to urban again; thus they may be misclassified.

The general observation of confusion matrices shows that there are some degree of misclassification, especially between farmland and forest classes (Tables 4.13, 4.14 and 4.15). This often happens over time when farmland changes to forest, and back to farmland again in the next image. This sort of change is unlikely in reality, as it takes a long time for forest regeneration, and is thus likely to be an error. Figure 4.10 illustrates a typical example of such switching of these classes. In 1987, the area marked with a circle (Figure 4.10) first appeared to be farmland, but the area then changed to forest in 1999, and then back to farmland in 2001. The reason for this might be contrary to the bare ground/urban misclassification problem, it might be caused by the fact that farmland tends to be misclassified as forest during wet years, when there are dense crops in the field. To investigate this error, climate data for the study area from 1984 to 2002 were analysed to observe annual variation in the climate and seasonality, and this was compared to changes in the classification results. Figure 4.8 shows variation in annual rainfall between 1984 and 2002, while Figure 4.9 presents the dry season rainfall (December to February for Benin City) in zone 1 of the Niger Delta. It is clear that 1999 was a wet year, and 2001 a dry year, which might be the reason why bare ground is more extensive during the dry year.

Farmland is sometimes included erroneously in urban class, despite the fact that urban class has the highest user accuracy throughout the years (Tables 4.13, 4.14 and 4.15). This error might be due to the fact that many fields are bare during dry season, when satellite data used in this study was obtained (See Section 4.2). Moreover, farmland resembles some building structures, usually buildings made from clay materials, during this period of the year.

Table 4.13. Confusion matrix for the 1987 ML classification image for the entire Niger Delta

		Reference Data (Sample Points) from Niger Delta Map						
		Urban	**Farmland**	**Forest**	**Mangrove**	**Water**	**Row Total**	**User Accuracy (%)**
Classified Map Landuse (Without DTR)	**Urban**	37	9	4	1	1	52	71.15
	Farmland	4	14	6	1	1	26	53.85
	Forest	2	4	23	3	1	33	69.70
	Mangrove	1	1	6	24	5	37	64.86
	Water	1	1	1	4	11	18	61.11
Column Total		45	29	40	33	19	166	
Producers' Accuracy (%)		82.22	48.28	57.50	72.73	57.89		

Overall Accuracy (%)	65.66
Kappa (%)	56.15

Table 4.14. Confusion matrix for the 2001 ML classification image for the entire Niger Delta

		Reference Data (Sample Pixels) from SPOT							
		Urban	**Farmland**	**Forest**	**Mangrove**	**Water**	**Bare Ground**	**Row Total**	**User Accuracy (%)**
Classified Map Landuse (With DTR)	**Urban**	44	0	0	0	0	9	53	83.02
	Farmland	0	16	4	0	0	0	20	80.00
	Forest	0	10	11	3	0	0	24	45.83
	Mangrove	0	1	0	8	4	0	13	61.54
	Water	0	0	0	6	19	0	25	76.00
	Bare ground	19	1	1	1	2	7	31	22.58
Column Total		63	28	16	18	25	16	166	
Producers' Accuracy (%)		69.84	57.14	68.75	44.44	76.00	43.75		

Overall Accuracy (%) 61.45

Kappa (%) 53.80

Table 4.15. Confusion matrix for the 2011 ML classification image for the entire Niger Delta

		Field Observed Landuse (Sample Points)							
		Urban	**Farmland**	**Forest**	**Mangrove**	**Water**	**Bare Ground**	**Row Total**	**User Accuracy (%)**
Classification Map Landuse (With DTR)	**Urban**	261	14	0	0	0	24	299	87.29
	Farmland	4	204	45	0	0	3	256	79.69
	Forest	1	23	249	45	0	4	322	77.33
	Mangrove	0	1	42	256	24	46	369	69.38
	Water	0	1	3	78	227	10	319	71.16
	Bare ground	165	89	1	16	0	34	305	11.15
Column Total		431	332	340	395	251	121	1870	
Producers' Accuracy (%)		60.56	61.45	73.24	64.81	90.44	28.10		

Overall Accuracy (%)	65.83
Kappa (%)	58.95

Misclassification of farmland as bare ground was also another problem, as shown in confusion matrices in Tables 4.13, 4.14 and 4.15. This might also be due to the effects of climate seasonality, whereby in dry years, fields that have been cropped are left fallow until the next rain. Many farmers in the Niger Delta practice bush fallowing and clear farmland during the dry season of the year, in order to prepare farmland for the next planting period. It is possible therefore, that surface reflectance from this cleared land will be the same as that of bare areas. Presumably, crops that have ripened in the dry season and have been harvested have not yet been replanted due to a lack of rainfall. As a result, the farmland class switches between bare ground and farmland, over the period of study, due to the fact that the area is sometimes cropped at the time of image acquisition.

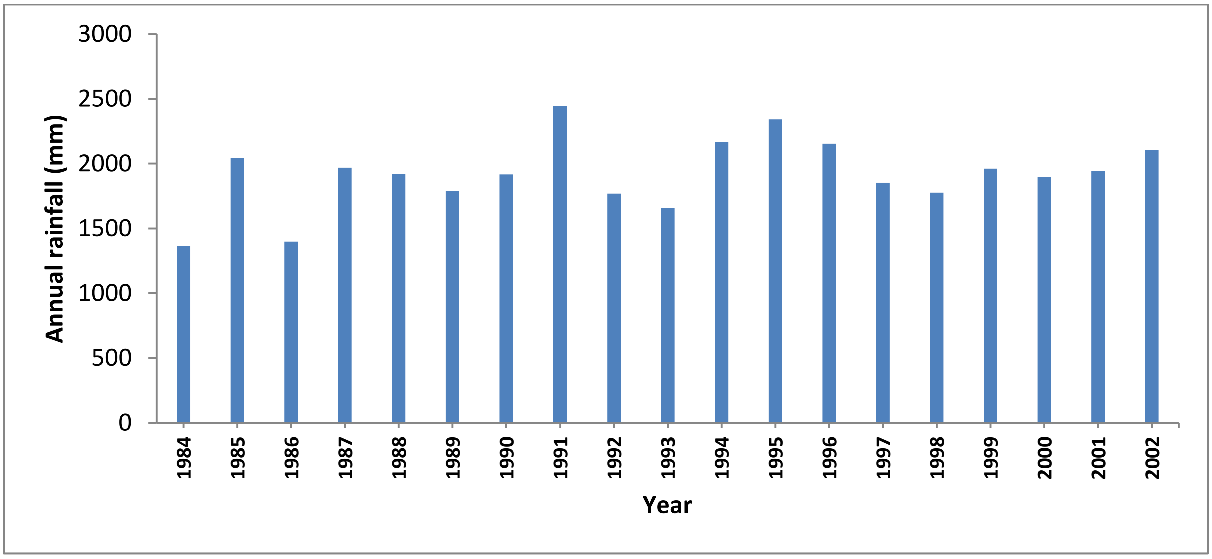


Figure 4.8. Chart showing total annual rainfall for Benin

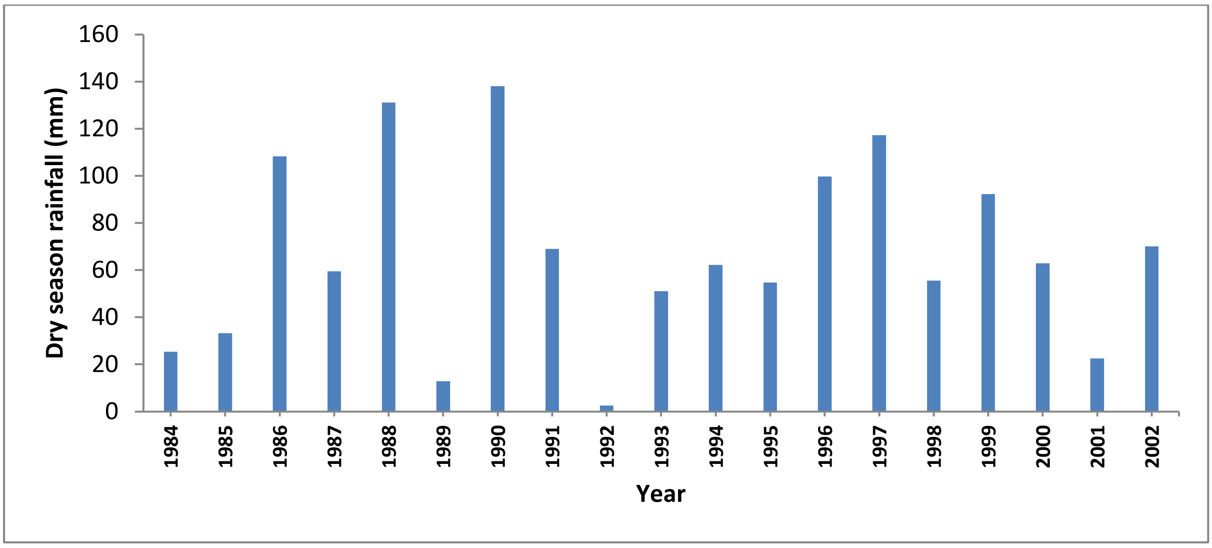


Figure 4.9. Chart showing total rainfall during dry season for Benin

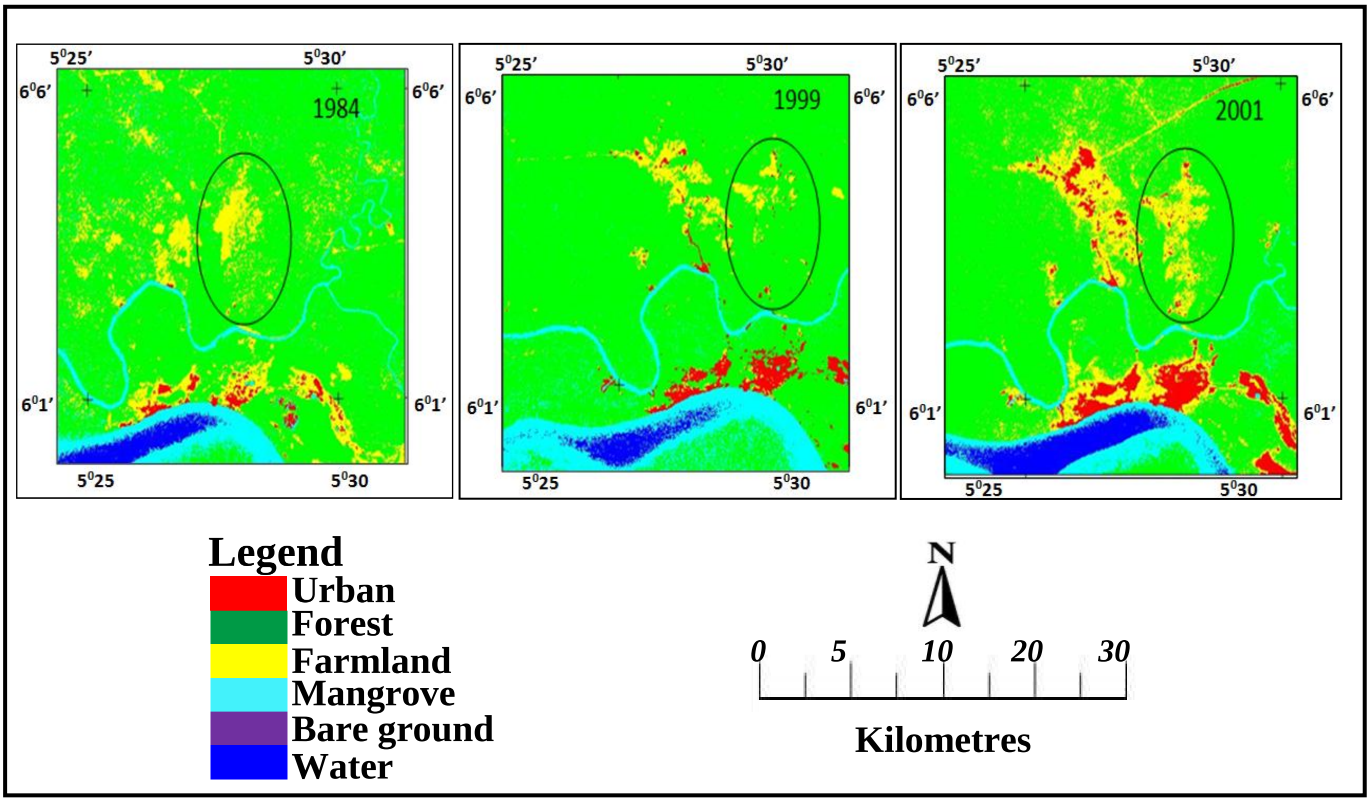


Figure 4.10. Switching of landuse classes due to uncertainties in classification

Overall and Kappa accuracies reveal that the ML classification results have several problems. In general, they were low for all classification maps produced in each year, where accuracy was assessed. In 1987 for example, overall and Kappa accuracies respectively were 66% and 56%, in 2001 were 62% and 54% while 66% and 59% for 2011 (Tables 4.14, 4.15 and 4.16). Previous landuse studies have also noted that classification and change detection using classification is a difficult process, the results of which may be affected by many factors (Du *et al*. 2002; Weng 2002; Lu and Weng 2007; Bhatta 2010; Perumal and Bhaskaran 2010). Typical among these are studies by Weng (2002) and Bhatta (2010), who observed that seasonality of climate causes change in apparent reflectance between urban area and open/ bare ground, thus affecting classification results. In addition, several other studies have reported classification uncertainties in agricultural landuse analysis (Geist and Lambin 2001; Akgn *et al.* 2004; Foody and Mathur 2004; Xiang *et al.* 2005; Yang and Liu 2005; Almutairi and Warner 2010). It has also been reported by Lambin *et al.* (2003) that the extent of cultivated land is determined not only by biophysical characteristics and agricultural practices, but also by the climatic conditions prevailing in the area.

A recent UK LCM (2011) report has also noted uncertainties in ML classification method, called "spectral confusion". The report recognised spectral confusion in landuse/landcover classes used in the study, especially confusion of arable field or open ploughed field, and roads or car parks. This confusion was basically because "an arable field that has been recently ploughed has little or no chlorophyll to absorb red light and will appear bright in this band as a road, a car park, an open-cast quarry, a sandy or shingle beach, or a limestone pavement" (Morton *et al* 2011). Other studies have also shown that if these surfaces have similar reflectance qualities for mid and near infra-red band, then it might be practically difficult to distinguish between them when performing classification (Du *et al*. 2002, Foody 2002). These studies have reported that complexities of the classification methods and effects of climate seasonality on Landsat imagery make monitoring and assessing changes in farmland cumbersome. The results from our analysis also support the view that effective landuse analysis, using classification methods, still remains a challenge, which depends not only on factors such as selection of image processing methods, but also the complexity of landscape in the study area and seasonality of climate. Therefore, there is a need for further analysis to eradicate this confusion of classes.

Given these problems, there is a need for a way of improving the accuracy of ML. One simple way of doing this is majority filtering (See Section 3.2.4), thus majority filtering method was applied in the first instance. The accuracy of majority filtering is presented in the next section.

4.1.3.12. The Majority Filter

The first step taken to eradicate the classification uncertainties was to perform majority filtering, in order to minimise 'salt and pepper' noise noted in the classification results. Since ML classification was performed on a per pixel basis, it is possible to transform the pixels within a defined image, in order to have the same values as the majority pixel value, by using a majority kernel. 3x3 and 7x7 types of filtering were carried out on the ML classification images, in order to find which of the two filters produce a better accuracy.

4.1.3.13. Accuracy Improvement Using the Majority Filter

The confusion matrices of the majority filter did not show much difference from that of ML classification accuracy. Table 4.16 compares the overall and kappa accuracies of ML and majority filtering for the entire Niger Delta using 1987, 2001 and 2011 classification images. It is clear that the accuracy result was not much affected after the filtering. When comparing the accuracy, the variations in the overall and kappa accuracies before and after majority analysis was not up to 10% for all the years. For example in 2011 image, overall accuracy was 66% before majority filtering, with little improvement of 67% after majority filtering. Kappa values show similar improvement, 59% and 61% before and after majority filtering respectively (Table 4.16). Previous studies have reported similar results (Huang *et al* 2002, Akgn *et al* 2004, Lu and Weng 2007, Otukei and Blaschke 2010). Thus, there is a need for better approach to reduce the classification uncertainties noted above.

Table 4.16. Comparison of the overall and kappa accuracies for the entire Niger Delta

	1987		2001		2011	
	ML Classification	**Majority Filtering Analysis**	**ML Classification**	**Majority Filtering Analysis**	**ML Classification**	**Majority Filtering Analysis**
Overall accuracy (%)	62	64	62	65	66	67
Kappa (%)	56	58	54	57	59	61

4.1.4 Decision Tree Reclassification (DTR)

To reduce the uncertainties outlined above (section 4.1.2), a Decision Tree Reclassification (DTR) method was then developed. The DTR method was implemented in the GIS environment to eliminate switching of classes that are unlikely, and allow changes that are possible. Figure 4.9 illustrates decision rules for the development of DTR method and how it was implemented in GIS. The blue decision rules represent DTR stages where the results of the second classified image were reclassified to first image; the green decision rules indicate DTR stages that were reclassified to second image; the yellow decision rules indicate DTR stages that were reclassified to a completely different class; while red represents no change of class during the DTR. The blue and green stages in Figure 4.9 show that the decision rules can work both back and forth. Thus, both the first and second classification maps (e.g. classification images of 1987 and 2001) were used to correct each other. Classification maps were exported from ENVI to ARCGIS, to perform DTR, following the DTR flow chart in Figure 4.9.

The DTR algorithm was implemented in a class specific manner as follows:

i. Urban and Bare Ground

The initial ML classified images show numerous misclassifications of bare ground to urban. In some images, areas of bare ground that occurred within urban areas, switched back and forth between urban and bare ground classes in successive image classifications through time, this behaviour is unlikely in urban areas and is more likely to be the result of misclassification of urban to bare ground. To overcome this, zones within a buffer of 3km were calculated around urban polygons. This was achieved using GIS overlaying techniques, and using urban vector ancillary data for the Delta (Section 4.1.1). Furthermore, given the rapid urban expansion in the region, it was decided that if bare ground occurred outside the buffer zone of an urban area it was kept as bare ground. But if the bare ground occurred within the urban buffer zone, it was reclassified as urban. The underlying rule here was that urban cannot change to any other classes (Figure 4.9 and Table 4.17). Given rapid urban expansion it is not possible for urban class to change to bare ground forest, mangrove and farmland. Thus, if this happened it was reclassified to urban.

ii. Farmland and Bare Ground

If landuse changed from farmland to bare ground, then, DTR reclassified such pixels as farmland. The reason for this rule is that it is clear from Section 4.1.3.11 that this type of change is common in the study area, due to seasonality of climate and agricultural practices of the people. The farmers practice bush burning during the dry period of the year, and clear the land to prepare farmland for the next planning period, yet this is usually the time imagery is acquired because it in the only time cloud free imagery is available. It is possible therefore, that surface reflectance from dry, open farmland and burnt areas will be the same as that of bare ground. The rule developed to consider this issue is that if bare ground changed to farmland, then the pixel was reclassified as farmland.

iii. Farmland and Forest

The change from farmland to forest is unlikely within few years, as farmland is generally encroaching on forests and even if the opposite were to occur, it takes not less than twenty-five (25) years for forest to develop to maturity (See Chapter two). Thus, if landuse changed between farmland to forest, DTR reclassified such pixels into farmland class. But, if forest class changed to farmland, DTR leaves such pixel as farmland.

iv. Forest and Mangrove

Both forest and mangrove cannot change to each other, within the time period of successive images, for it also takes about twenty-five years for mangrove to grow to maturity. Thus, if a class changes from (say) forest to mangrove, DTR reclassified such pixels as forest. Therefore, the rule is that forest cannot change to mangrove, and mangrove cannot change to forest. If they do, they are reclassified back to their original class.

v. Bare Ground, Forest and Mangrove

There is little chance for bare ground to change to forest or mangrove within few years. Thus, if this occurs, it is reclassified to farmland (the reason is as discussed in section ii above). Bare ground will only retain its class when there is persistence in this class over the years (red DTR stage in Figure 4.9).

4.1.4.1. **Accuracy Assessment of DTR**

The classification results appear to have been significantly improved after applying the DTR. This is evident in comparing pre-DTR confusion matrices (Tables 4.14, 4.15 and 4.16) with post-DTR application (Tables 4.17, 4.18 and 4.19). Figure 421.12 presents a sample of a classified 2001 image mosaic before and after using DTR. Much bare ground within the urban class is obvious in Figure 4.12A, when no DTR has been applied and there is much misclassification between urban and bare ground as well as farmland and bare ground classes, which was reduced after applying DTR (Figure 4.12 B).

Comparison of pre and post-DTR accuracy (Tables 4.17, 4.18 and 4.19) shows a significant improvement in results with overall accuracy and kappa improved by over 20%. The Overall Accuracy and Kappa accuracy was 64% and 58% for 1987 before DTR, but improved to 84% and 97% respectively after DTR. The DTR also improved the accuracy classification in other years as shown in Table 4. In general, the overall accuracy and kappa were high throughout the years, though highest was obtained for 2011 (Table 4.19). On the whole, the results present in Tables 4.17, 4.18 and 4.19 have shown a general DTR accuracy. The reasons for the increase in accuracy is because the misclassification or inter-class error noted in the results (before DTR) are due to confusion of: bare ground with urban and farmland impacted areas; forest with farmland (especially areas of farmland within forest as observed during field visit); and mangrove with water. Almost all the classes improved the classification accuracy after DTR, and the user and producers' accuracy of urban, bare ground and forest show that they are responsible majorly for the improvement in DTR accuracy.

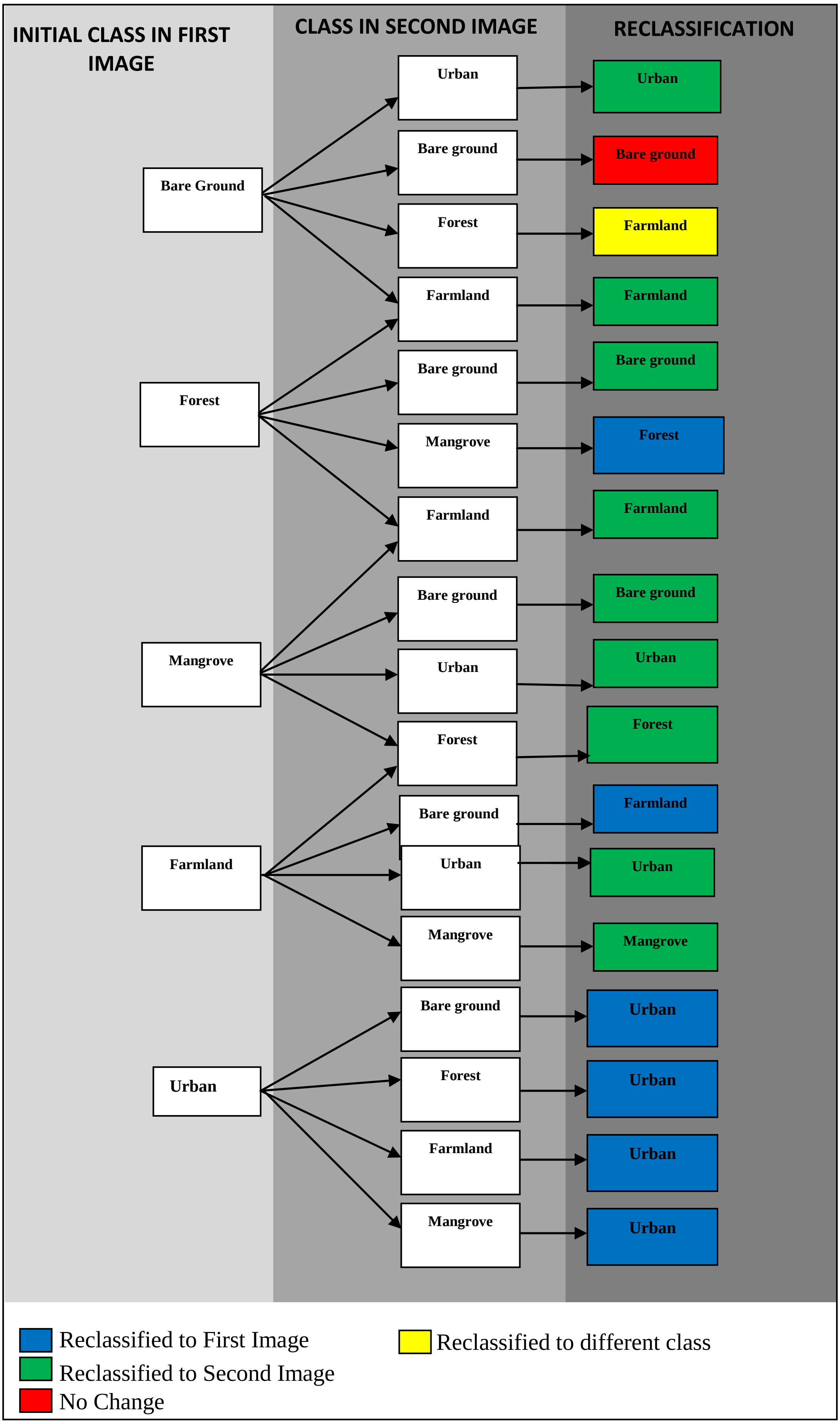


Figure 4.11. Flow diagram of DTR rules used to reduce errors in image classification

In the case of bare ground and urban classes, for instance, user and producers' accuracy improved by 22% and 13% respectively, but the forest class contributes even more, by approximately 38%. Mangrove improves a little (8%) and contributes to the improvement in DTR accuracy. Previous studies have shown that a Kappa of 65% and above is acceptable in landuse classification (Lambin *et al* 2003; Boakye *et al* 2008). Therefore, kappa value of 89.78% obtained for the 2011 image in the present study suggests an acceptable degree of agreement between landuse classification maps produced and the actual reality on ground (Table 4.19). Given the accuracy improvement over other methods, this method was applied to all maximum likelihood classifications conducted during this study.

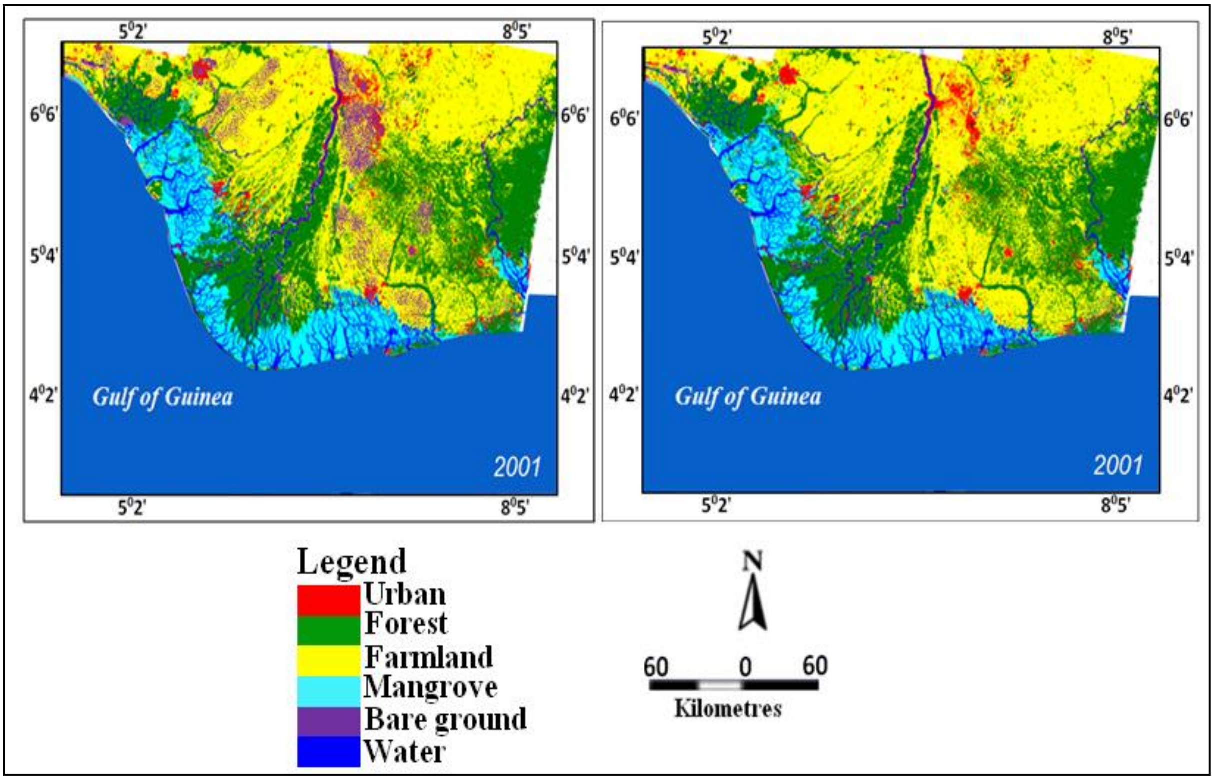


Figure 4.12. Classified maps of the Niger Delta (2001 image), comparing pre-DTR (left) and post-DTR (right) classification maps.

Table 4.17. Confusion matrix for 1987 images after applying DTR

		Reference Data (Sample Points) from Niger Delta Map						
		Urban	**Farmland**	**Forest**	**Mangrove**	**Water**	**Row Total**	**User Accuracy (%)**
Classification Map Landuse (Without DTR)	**Urban**	45	3	0	0	0	48	93.75
	Farmland	5	30	3	0	0	39	78.95
	Forest	1	1	28	3	0	32	84.85
	Mangrove	0	3	3	22	4	32	68.75
	Water	0	0	0	1	14	15	93.33
Column Total		51	37	34	26	18	166	
Producers' Accuracy (%)		90.20	83.78	82.35	84.62	77.78		

Overall Accuracy (%) 83.74

Kappa (%) 79.13

Table 4.18. Confusion matrix for 2001 images after applying DTR

		Reference Data (Sample Pixels) from SPOT							
		Urban	**Farmland**	**Forest**	**Mangrove**	**Water**	**Bare Ground**	**Row Total**	**User Accuracy (%)**
Classified Map Landuse (With DTR)	**Urban**	44	0	0	0	0	1	45	97.78
	Farmland	2	30	3	0	0	0	35	85.71
	Forest	1	2	30	3	0	0	36	83.33
	Mangrove	0	1	1	15	5	0	22	68.18
	Water	0	0	0	3	15	0	18	83.33
	Bare ground	0	0	2	1	0	7	10	70.00
Column Total		47	33	36	22	20	8	166	
Producers' Accuracy (%)		93.62	90.91	83.33	68.18	75.00	87.50		

Overall Accuracy (%)	89.16
Kappa (%)	81.19

Table 4.19. Confusion matrix for 2011 images after applying DTR

		Field Observed Landuse (Sample Points)							
		Urban	**Farmland**	**Forest**	**Mangrove**	**Water**	**Bare Ground**	**Row Total**	**User Accuracy (%)**
Classification Map Landuse (With DTR)	**Urban**	374	8	0	0	0	3	385	97.14
	Farmland	4	385	17	0	0	0	406	94.83
	Forest	1	3	301	21	0	0	326	92.33
	Mangrove	0	1	20	300	19	0	340	88.24
	Water	0	0	0	20	304	0	324	93.83
	Bare ground	5	5	1	5	0	73	89	82.02
Column Total		384	402	339	346	323	76	1870	
Producers' Accuracy (%)		97.40	95.77	88.79	86.71	94.12	96.05		

Overall Accuracy (%) 90.85

Kappa (%) 89.78

Table 4.20. Comparison of the overall and kappa accuracies for pre and post-DTR

	1987		2001		2011	
	Pre-DTR (Majority Filtering Analysis)	**Post-DTR**	**Pre-DTR (Majority Filtering Analysis)**	**Post-DTR**	**Pre-DTR (Majority Filtering Analysis)**	**Post-DTR**
Overall accuracy (%)	64	84	65	89	67	91
Kappa (%)	58	79	57	81	61	90

4.1.5 Post-Classification Analysis and Assessment of Intra-Annual Rate of Landuse Change

Post-classification comparison was carried out after classifying the images separately for the different time periods (from 1984 to 2011), and the results presented in the form of tables and charts. Results from post-classification comparisons helped in identifying the percentage change, trend and rate of change in landuse over the study periods. To facilitate post-classification comparisons, the first task was to develop a table showing the area in km^2 and the percentage change for each year, which was measured using equation 4.5.

$$Int_{LUC} = \frac{[\log C_{t1} - \log C_{t0}]}{t_1 - t_0} \times 100 \qquad (4.5)$$

Where Int_{LUC} is the intra-annual landuse change, t_1 is final year, t_0 is initial year and C is the landuse class percentage (Onojeghuo and Blackburn 2011).

Furthermore, to examine differences in landuse change within the forest zone in the Delta, lowland rainforest and freshwater swamp classes were introduced, as these forest distinctions are important ecologically, and in terms of landuse. This was achieved by performing post classification reclassification of forest, using shape files of rainforest and freshwater swamp forest generated in Chapter two. Detailed discussions of shape files and other ancillary data used are presented in Section 4.1.7.1.

To assess qualitative and quantitative rates of change, cross-tabulation method was employed. Cross-tabulation method was used as a means of determining spatial and temporal rates of change from a particular classified landuse image, to the other at the later date. The classified images were compared using the pairs of consecutive years for the periods of 1987 to 2001, and from 2001 to 2011. Overall changes during the period of study were also calculated, using classified image pairs of consecutive start (1987) and end (2011) years, as detailed in Section 4.1.5.1 below.

4.1.5.1 Landuse Change Maps Production

Landuse change maps were produced and change detection statistics were derived for each of the landuse classes as follows:

$$\mathbf{LUC} = \mathbf{LU_1^i} - \mathbf{LU_0^i} \tag{4.6}$$

Where ***LUC*** represents the landuse change map, ***LU*** is the landuse class ***i*** (say urban), in a year ***1*** (say 2011), and previous year ***0*** (say 2001). LUC maps were produced to monitor the rate of change in LU within the periods. Figure 4.11 shows the procedures followed in this research to analyse LUC. Green labels are different stages of analysis, and blue shaded stages were carried out after classification and post classification analysis.

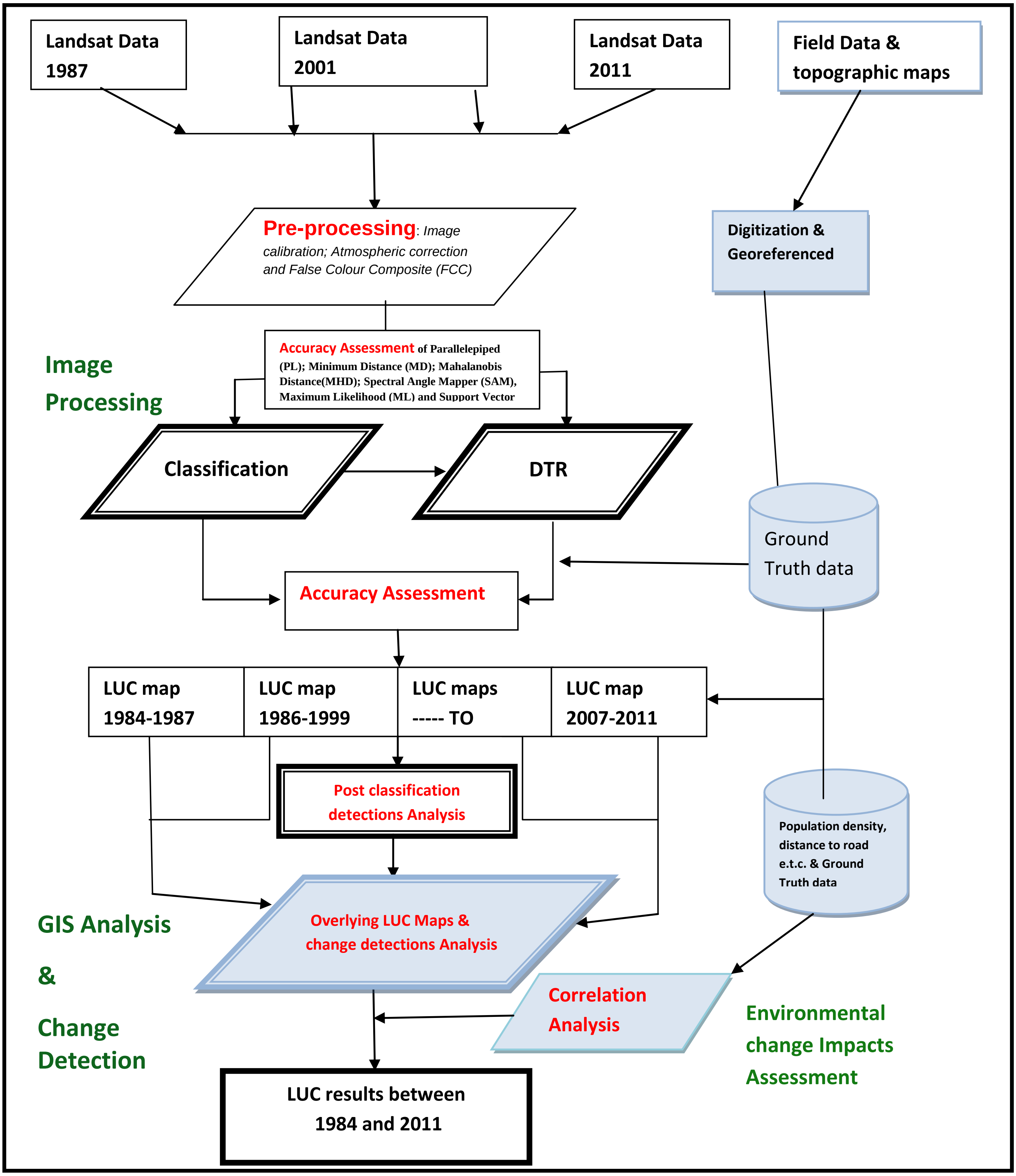


Figure 4.13. Summary of landuse change detection processes applied in this study.

4.1.6 Vegetation Degradation Analysis

The Normalized Difference Vegetation Index (NDVI) was employed to assess the rate of vegetation degradation in the region. Figure 4.14 shows the systematic procedure by which the vegetation degradation was calculated. The results from NDVI analysis help in measuring the trend of vegetation degradation in the region. Computation of NDVI was carried out from reflectance in the red and near infrared (NIR) bands of the images. Therefore, these bands were radiometrically and atmospherically corrected before applying NDVI (See Section 4.2.1 for the details of atmospheric correction).

4.1.6.1 NDVI Image Differencing Method

NDVI Image Differencing method was used to monitor the degradation of forested areas. Pairs of consecutive Multi-dates NDVI images were subtracted (1984-1987; 1987-1999; 1999-2001 and 1984-2011), to produce maps showing change in vegetation over the period of time. GIS overlays were then also used to calculate vegetation changes within the different forest types and in protected areas. To obtain NDVI values for forest only, the forest class was used as a mask to exclude the NDVI of other landuse classes.

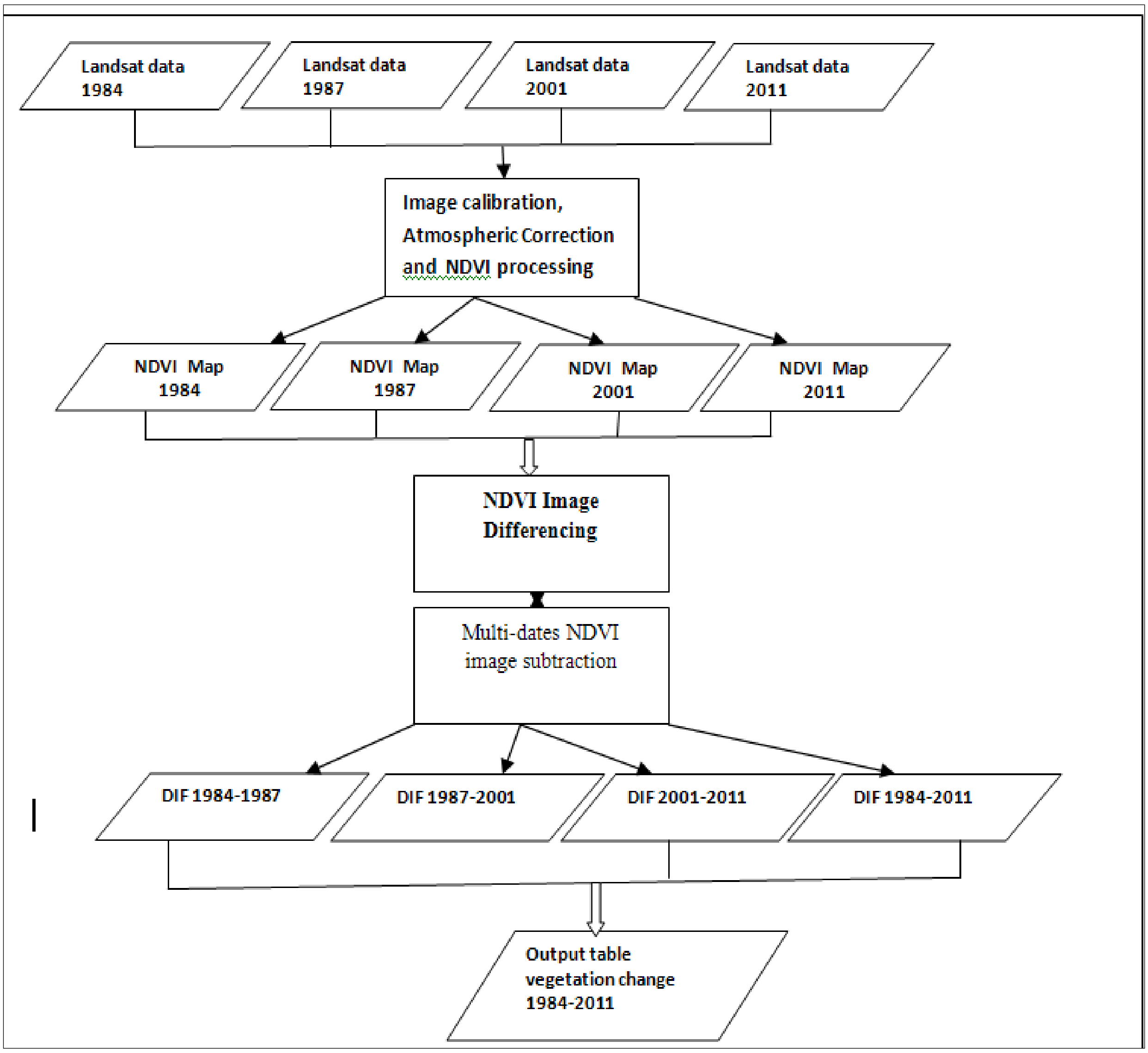


Figure 4.14. Summary of vegetation change detection procedures

4.1.7 Selection of Case Studies of Environmental Change in the Niger Delta

A review of Niger Delta has shown that there are over seventy (70) forest reserves in the region. Therefore, to examine the rate of deforestation and degradation in the forest reserves, specific case studies were selected for this research. Selected cases were derived from the coverage of satellite image data, percentage rate of deforestation and extent of loss in the forest reserves as reported in the previous studies. Information about degraded forest reserves, as in the literature reviewed in chapter two of this thesis, was also used to target some reserves for case studies. Three major characteristics used for the selection were: (1)

areas of forest lost in km^2 (2) areas of forest remaining in km^2 and (3) rate of degradation within the forest reserves as determined by NDVI. Shape files of the forest reserves in the Delta, obtained from Ramsar Convention, were used to obtain information about the location and areas of the forest reserves. The results of spatial and temporal changes in different case studies are presented in the next chapter.

4.1.7.1 Merging Ancillary Data with Classified Landuse Maps Production

Ancillary data were merged with the classified maps in a GIS environment. The ancillary data were initially geocoded in such that they were registered with the classified images. Details about ancillary data used and methods of geocoding have been detailed in Section 4.1.1.2. Overlaying approach in GIS environment was used to merge ancillary data and classified maps. Overlaying was performed by integrating different ancillary data layers, which have been converted to vector data. A prior knowledge of the study area (e.g. original ecosystem status, location, size, relationship with other cover types, shape, socioeconomic data, etc.), were also used to direct and support the incorporation of ancillary data with classified image. Each ancillary data was combined with classified image for different purposes. Generally, they were used after classification in order to derive more information about the extent, drivers and implications of landuse change observed through classification.

4.1.8 Methods of oil spill mapping

Three commonly used methods for oil spill detection using Landsat imagery were used to try and map an oil spill in the Delta: Visual interpretation of colour composites, Classification and Band ratio differencing methods. Two locations of recent oil spills reported in the literature were evaluated: Oboolo and Bomu (UNEP EA 2011). The quantity of oil spilled and area covered by the spill was higher in Bomu, compared to Oboolo, according to UNEP EA (2011). However, all Landsat images available for Oboolo were covered by cloud. Thus, a case study of the January 3rd 2007 oil spill in Bomu was assessed in order to examine the potential of Landsat data in mapping the oil spill. A Landsat ETM image of the January 19th 2007 was used as it was the cloud free image closest in time to the spill. The image was radiometrically corrected to surface radiance and submitted to further restoration analysis as discussed in Section 4.1.2. Visual interpretation of colour composites images was carried out, while Maximum Likelihood (ML) supervised classification was performed as discussed in Chapter 4 (Section 4.1.3). NDVI was also performed as recommended by Souto *et al.* (2006).

4.1.9 Possible Drivers of Landuse Change in the Niger Delta

Correlation analysis was used to assess possible drivers of landuse change in the Niger Delta. The main aim of correlation analysis is to evaluate the relationship between deforestation and distance to roads, urban expansion and population density, and between farmland expansion and deforestation. GIS vector overlay maps showing the road network were used in the analysis. The buffer operation was used to create zones of specified widths around the major roads. The distance to roads was calculated as a series of buffers of 100m expanding from each arc of the road network. The buffers had intervals of 0-1 Km, 1-2 km, 2-3 km, 3-4 km etc, and this were used to see what landuse fell within each distance zone. The majority of roads in the Niger Delta are gravel roads, thus each road segments was therefore treated as equally suitable for transportation of logs from forests. Data generated from buffered layers were used in querying how deforestation changed with distance from roads.

The correlation analysis started by testing the normality of each variable (potential drivers of landuse change) used in the analysis, using Quantile - Quantile (Q-Q) plots (Figure 4.15). It is clear from the Q-Q plots that all variables used; fall in a straight diagonal line with a positive slope as shown in Figure 4.15. The result of Q-Q plots indicated that the variables used follow approximately a normal distribution, thus Pearson correlation coefficient (R^2) was used to calculate between observed landuse change and potential drivers of such change. Population densities were derived from population data described in Section 4.1.2.1. This data were then correlated with deforestation.

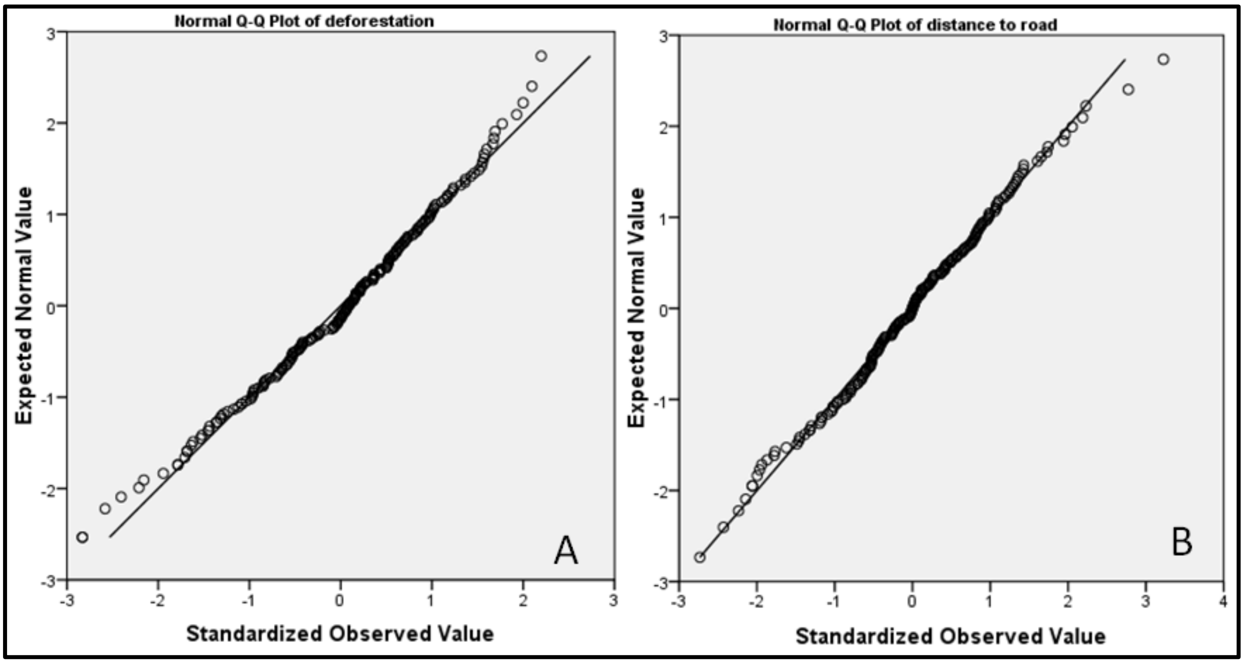


Figure 4.15. Examples of Q-Q plots for deforestation (A) and distance to road (B).

4.2 Social Survey Methodology: Assessment of Social Implications of Remote Sensing Findings

Social survey was conducted in two stages: 80% was carried out during initial field work in 2011, while about 20% were done in 2013, for better understanding of the drivers of changes as observed in remote sensing results and the societal implications of these changes. Both quantitative and qualitative social data were collected and used. The study used questionnaires to collect quantitative data, while focus group discussion and interview methods were used to collect qualitative data. Multiple social data relating to the impacts of the environmental changes observed from remote sensing analysis were collected. The data were used in order to triangulate the results and findings from remote sensing; and used these data to validate the findings from remote sensing, so as to enhance research quality of environmental change assessment in the study area.

Since questionnaire, interview and focus group methods have different merits and limitations; they were used to test the reliability of the results from remote sensing techniques. Consequently, the present study uses three methods of collecting social data because they are effective in the Niger Delta, not only for the purpose of triangulation and effectiveness, but also because the strength of interview and focus group methods complements the limitations of the questionnaire method (Clark and Creswell 2008, Marshall and Rossman 2011, Creswell and Clark 2011). Triangulation in this study means applying different data collection methods (mixed methods) within one research or study in order to validate the research outcomes (Saunders *et al* 2009, Symon and Cassell 2012). Reliability, according to Saunders *et al. (*2009), is the extent at which research results and findings can be generalised to all relevant contexts and other parts of the study area. Validity in the context of this research refers to the extent to which data collected is true (Veal 2005).

Moreover, to validate the findings from remote sensing results, the relevant data needed in each location was collected. For example, the remote sensing analysis demonstrates rapid deforestation in Okomu (a major forest reserve), impacts of urbanisation in Okitipupa/Irele; oil production impacts in Eket and Oboolo and, other environmental changes resulting from the construction of artificial canals in Tsekelewu. These issues were addressed in social survey by: (1) in Okomu, social data relating to the implications of deforestation on people and biodiversity were collected (2) in Okitipupa/Irele, social data on the perception of people and the impacts of urbanisation on their social activities were collected, (3) in Eket and Oboolo social data relating to oil production impacts were collected (4) in Tsekelewu, social data collected are those relating to contamination of waters and the environment, through inflow of salt water from the ocean resulting from construction of canals. Therefore in the subsequent sections, detailed description of methods by which the social data were collected and analysed is presented.

4.2.1. Questionnaires Survey Method

The Questionnaire survey method was used in this research because it is a technique of eliciting different data from target population. This approach is not without its limitations. A major limitation of the questionnaire survey approach, according to Parfitt (2005) is that it does not allow the respondents to fully express their feelings in details, knowledge and experiences about the subject matter of the research. Similarly, Parfitt (2005) further detailed important challenges in the implementation of questionnaire method as: (1) the selection of an appropriate location unit (2) the validity and reliability of the method, in terms of the selection of an appropriate sample of respondents and considering different sampling strategies that can be adopted and the (3) selection of an appropriate time of the day when the questionnaires will be conducted. The present study thus carefully considered these issues for questionnaire administration and is discussed below.

The selection of location where questionnaires were administered was based on the findings of remote sensing analysis. Questionnaires were administered in the major locations of suspected environmental change as seen on the results from remote sensing. The results of remote sensing analysis show three major regions of environmental change in the Niger Delta, with significant impacts on the physical environment, social and economic state of people, for example, the Ondo/Delta, Bayelsa/Imo and Rivers/Akwa Ibom regions. Of these three regions, only two (Ondo/Delta and Rivers/Akwa Ibom regions) could be visited for questionnaire administration, due to poor security in the other regions. Even in the regions visited, extra security consciousness was required during the field work due to frequent unrest in the region. The security agencies for the local communities were informed about the field work and some field security guards were appointed to safeguard in some locations. Questionnaires were also administered in the Tsekelewu, Eket and Oboolo communities. Tsekelewu is the largest oil field located in Ondo/Delta region while Eket and Oboolo are in "Ogoni-Land", the major oil producing area located in the Rivers/Akwa Ibom region (Figure 4.16). Although, previous studies have reported occurrence of oil spills and other pollutions resulting from oil production in the Niger Delta, their analysis lacked adequate data on the spatiotemporal quantity of the spills and the perspectives of people affected (Atakpo and Ayolabi 2009; Enemugwem 2009). The main focus of the questionnaires therefore, was to discover the perceptions of the local people of the social and health impacts of oil production activities on their communities.

Two hundred and fifty (250) questionnaires (Appendix D) were administered around the Tsekelewu, Eket and Oboolo communities, where oil production impacts and construction of artificial canals by oil companies had been indicated by the remote sensing investigation. One hundred (100) questionnaires were administered in Tsekelewu, one hundred (100) also in

Eket and fifty (50) in Oboolo. The numbers of questionnaires administered in each location were contingent on the population size of the communities. A description of the composition of questionnaires, their administration and the nature of door-to-door sampling are presented in Table 4.22. Detailed descriptions of sampling methods, and times of the day when the questionnaires were distributed were discussed below, under validity and reliability of questionnaires approach.

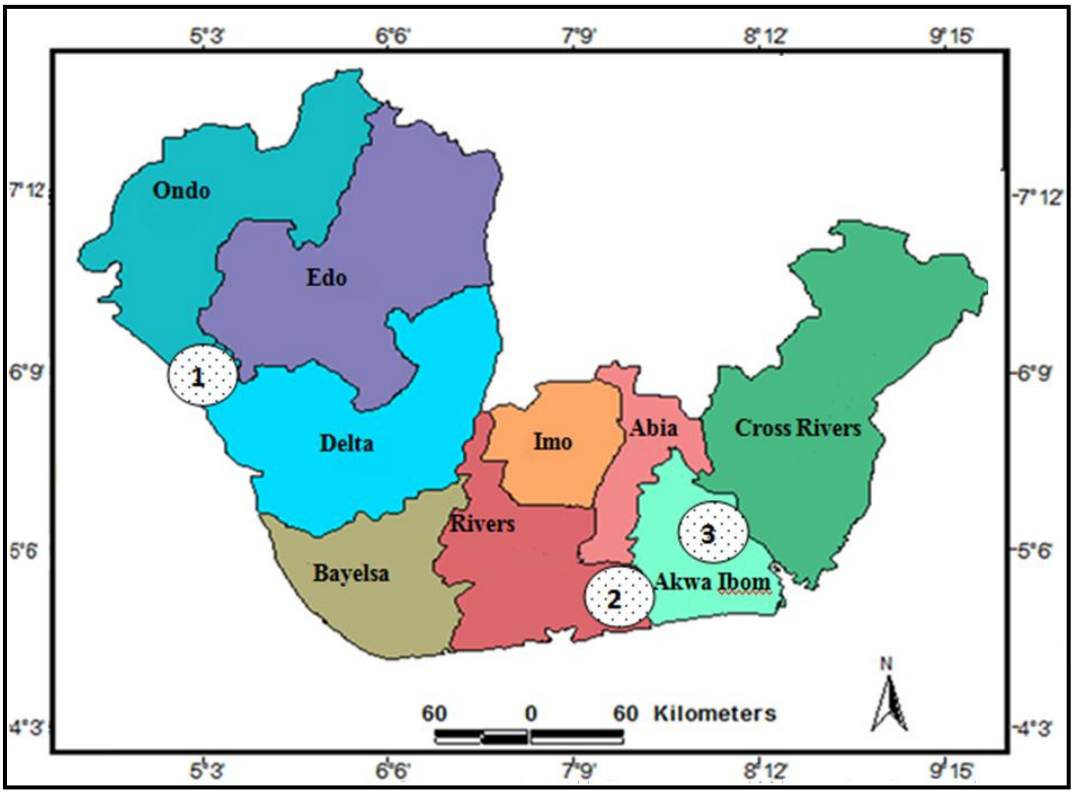


Figure 4.16. Map of Niger Delta showing locations of major oil pollution where questionnaires were administered during field work: 1.Tsekelewu 2. Oboolo and 3. Eket .

Table 4.21. Composition of questionnaires administration for this study

Location	Tsekelewu	Eket	Oboolo
Major Environmental change observed from remote sensing analysis.	Oil pollution and pollutions from salty water from artificial canals constructed by Chevron oil company.	Oil pollution and contamination of drinking water from oil production activities of multinational oil companies.	Oil pollution and contamination of drinking water from oil production activities of multinational oil companies.
Number of questionnaires administered.	100	100	50
Age range of respondents.	25-55 years	25-55 years	25-55 years
Sampling method used.	Systematic sampling	Systematic sampling	Systematic sampling
Questionnaires administration approach	Face-to-face	Face-to-face	Face-to-face

4.2.2. Validity and Reliability of Questionnaire Administration

To make sure the data collected from the questionnaire are reliable, a face-to-face questionnaires administration was carried out so as to improve the rate of responses for the questionnaires administration. Several sampling methods have been used in the literature to conduct questionnaires through sampling from a large population. Such methods include simple random sampling, systematic, stratification, multi-stage and non-probability sampling such as quota sampling. Detailed descriptions of these methods are presented in Section 4.5.1 of this thesis. Out of these methods, systematic sampling method was used to select households, where the questionnaires would be administered, because it has the merits of cost effectiveness and also not biased (Harrel and Bradley 2009, Symon and Cassell 2012). Also, this study uses this method of systematic sampling because of its greater precision, compared with other sampling methods, and because it is possible to use a smaller sample size and thus saves time and money.

The household where questionnaires were administered was calculated by dividing the total member of house units in each community by the sample size required. This was achieved by applying this simple equation:

$$K = \frac{N}{n} \tag{4.7}$$

Thus, sample households were drawn by selecting every K where N is the total number of the households in the community and n is the sample size desired. For example, in a community of say 200 households and a sample size of 10, then K = N/n = 200/10 =20th. The sampling interval is then added to the number of the randomly selected member households to identify sample house number and the process is repeated until the required numbers of houses have been drawn.

Two major problems were encountered while using this systematic sampling method during the questionnaires administration: (1) How to select the starting point and (2) What will be the appropriate time of the day to meet the household to conduct the questionnaires. To eliminate these problems, the starting point was randomly selected by numbering the beginning section of the household list and selecting a number using random number generated on a calculator. The household lists were collected from leaders of the communities, where the questionnaires were conducted. Furthermore, since the majority of people in these communities are from an agrarian society, who usually goes to their fields in the morning, the questionnaires were administered during the evening when they were back. Thus, the questionnaires were distributed during a 'neutral' time, according to Saunders *et al* (2009), a period of time when the respondents were not too tired, and it was not too early in the morning, so that the questionnaires would not be seen as disturbance for them.

Another research precaution put in place during the questionnaire administration was that the questionnaire findings were collected in a way that ensures that the information being supplied is confidential. The leaders of each community did not know what the people below him were saying in the questionnaire and vice versa, so as to avoid bias about satisfying the community leader because parts of the questions addressed in the questionnaires were the participants' assessment of the efforts of their leaders and the government in combating environmental pollution and changes in their communities. This was done because the majority of the respondents might not want the leaders to be angry with them about the information being given, relating to their leaders' effort. The questionnaires and other field documents are presented in Appendices A to K.

4.2.3. Interview Methodology for Data Collection

A one-to-one interview approach was used in order to obtain in-depth background information on historical, socio-economic and health factors, that could be of assistance in the interpretation of the information obtained from the results of remote sensing image analysis. Thus, a semi-structured interview approach was used. A semi-structured interview is a method of collecting social data through verbal interchange, also in semi-structured interviews, a researcher attempts to elicit information from another person by asking questions, as there are opportunities to probe and ask for clarifications, if need be (Muise and Olson 2003, Smith and Osborn 2007). The major limitation of this approach, according to Harrel and Bradley (2009), is that only one person can be interviewed at a time. The study used this approach because studies have shown that it is a better means of obtaining detailed information about the experiences of the participants in relation to the research (Zhang and Wildemuth 2003, Muise and Olson 2003, Smith and Osborn 2007, Frankfort-Nachmias and Nachmias 2008, Harrel and Bradley 2009). Likewise, the major advantage of this method over questionnaires is that respondents build a trust and relationship with the interviewer and in the process; it is more likely that the respondents feel they can reveal personal feelings. Although, a list of predetermined questions were prepared before starting the interview, the semi-structured interview approach used in this study unfolds in a conversational manner, offering the participants opportunities to explore experiences relating to the impacts of environmental change.

Health professionals were interviewed about the potentials for and occurrences of health issues associated with environmental pollution from oil production and oil spills in the communities, where they provide health services. Two health professionals were interviewed in Tsekelewu, four in Eket and one in Oboolo (Table 4.23 and Figure 4.17). These were all the health professionals who were available for the interview in each location. No health practitioners were interviewed in Okitipupa/Irele and Okomu. This is because the major environmental changes in this location, based on the results from remote sensing analysis, were urban expansion and deforestation. The interviews started with the questions that the interviewer felt that health professionals would be comfortable answering, and thought-provoking questions relating to impacts of environmental change on peoples' health in the Niger Delta (as seen in remote sensing analysis), were asked later when the interviewees were feeling more comfortable. Based on the findings of remote sensing analysis, the key social research questions that were asked here include: What are the effects of environmental pollution from oil production on peoples' health in your village/town?; Are there reported cases of health effects of oil exploration activities in this community?; Do people report to your clinic or find other medical means? etc. The transcripts of the interviews (audio records) are presented in a compact disc (CD), and submitted with this thesis to the Library of the King's College London.

In addition, a member of the Nigeria Conservation Foundation (NCF); the Director of the Institute of Ecology at the Obafemi Awolowo University, Ile-ife, Nigeria; a staff member of each of the Okomu forest reserve, Uwet Odot forest reserve and Bayelsa National Park and local people in Okomu, Gilli-Gilli and Uwet Odot communities were also interviewed on their experiences and knowledge of environmental degradation going on around their communities. These were the people who have adequate local knowledge and experience of environmental degradation in the Delta.

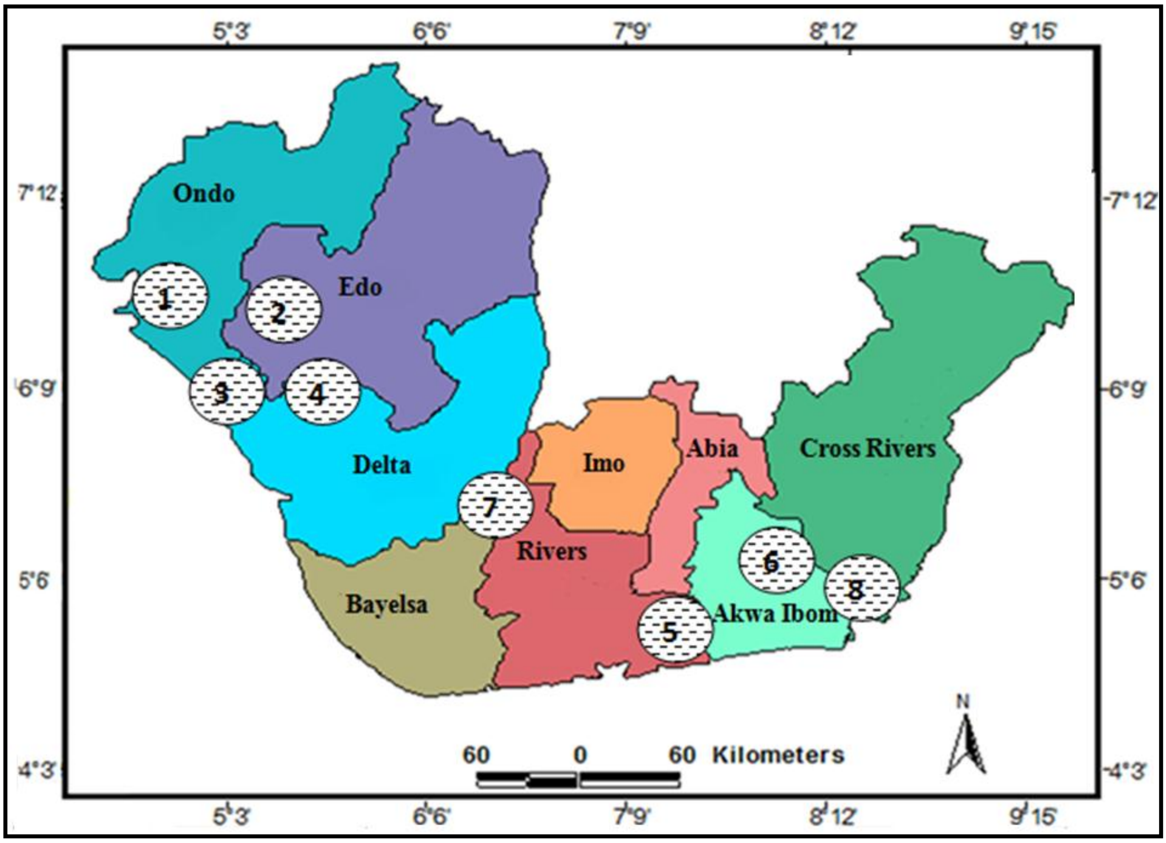


Figure 4.17. Locations where interview and focus group discussions were carried out during field work: 1. Okitipupa/Irele 2. Okomu 3. Tsekelewu 4. Gilli-Gilli 5. Eket 6.Oboolo 7. Bayelsa National Park and 8. Uwet Odot forest reserve

The major questions that were asked concerning the implications of deforestation to both humans and biodiversity were: What do you think has been the significant changes in the forest reserve in the Niger Delta over the last 30 years, in terms of deforestation, the proportion of flora/fauna, and changes in landcover/landuse?; What are the major causes of the deforestation in the Delta?; What are the impacts of these changes on people living in the Delta and on the wildlife in these forests?; Do you think that the increase in deforestation rate and other environmental changes in the Delta are results of lack of political will? etc. In each interview, the questions were not always asked in the order listed, but rather, the discussions were allowed to unfold in a conversational manner to enable the participants express their feelings and experiences. At the end of each interview, the list of questions and interview schedule were checked to make sure that all the questions have been asked and answered at some stage during the interview.

Although, there were no sensitive issues in the interview questions asked, notwithstanding, the interviewees still needed to be probed more, before some facts about the implications of environmental changes noted from the results of the remote sensing analysis could be obtained. The interview questions asked are listed in Appendices E, F, G and H.

4.2.4. Validity and Reliability of Interview Method

Table 4.21 illustrates detailed descriptions of the composition of the one-to-one interviews conducted. The interviewees were asked to give a time that they could be available when there would be no disruption. Furthermore, a place where they would have freedom to express their views was chosen, so as to not influence the responses from them.

4.2.5. Focus Group Discussion Method

Focus group discussion method was chosen and used in this study, since it is a good way of gaining insight into participants' understanding and their views about environmental changes around them and also to look at how such views differ by social groups. More information can be obtained using focus group discussion since many people can discuss on a research issue simultaneously, unlike one-to-one interviews (Zhang and Wildemuth 2003, Smith and Osborn 2007).

Therefore, the aim of conducting focus group discussions, is to bring together for discussion, people who were known to have had certain experiences about the impacts of environmental changes in their communities. The general research question for this focus group is to know how people in the Niger Delta feel about the environmental changes going on around them and how they understand social, economic and health impacts of these changes. In view of this, different sets of questions were asked in different locations in the Niger Delta, which is because different types of environmental changes were apparent in different locations in the Delta, based on the results from remote sensing. Thus, the major focus of discussion in Okitipupa/Irele was the impacts of urban expansion on social and economic activities of people in the community while the main focus question in Okomu is to have in-depth information about the social and economic implications of deforestation on the people of the community. The main research question for group discussions in Tsekelewu, Eket and Oboolo was to have better understanding about the perceptions of people on social and health impacts of inflow of salty water and contamination from oil production in the community. Therefore, this focus discussion enabled a better understanding of the way people in these communities make sense out of environmental changes around them. Those who showed most interest in the topic, aim and objectives of this research and responded actively during questionnaires administration were selected. Likewise, the transcript (audio records) of focus group discussions is presented in a CD with the copy of this thesis, submitted to the Library of the King's College London.

4.2.6. Validity and Reliability of Focus Group Discussion

The settlements visited in the sampling areas consist of several people with different tribal languages. Yoruba is one of the tribal languages in Western and central parts of the Niger Delta, but some tribes speak Urhobo and Igbo in other regions of the Delta. However, Pidgin-English language is developed and used by people in the Niger Delta as a simple means of communication among all these named tribes. Thus, the majority of focus group discussions were conducted in Pidgin-English language since this was the only common language for communication within the different tribal people. However, Yoruba language was used in Okitipupa and Irele where it is mostly spoken.

It has to be noted that the transcription of the audio records taken from sample areas, where focus group discussions were carried out, was translated from Yoruba and Pidgin-English Languages to English language. Although there were some words, adages and proverbs that were used by participants during the focus group discussion, that were very difficult to interpret and transcribe directly to English language. This limitation was reduced by finding the word or a group of words in English that best infer and nearest in meaning to the words used. The summary and results of transcriptions from audio field records are presented in Section 5.5.1 in the results chapter, while analytical results from questionnaires and interviews on health impacts of environmental changes are presented in Section 5.6.

Table 4.22. Composition of interview and focus group discussions for this study

Location	**Okitipupa/Irele**	**Okomu**	**Tsekelewu**	**Eket**	**Oboolo**
Major Environmental changes observed from remote sensing analysis.	Urban expansion and deforestation.	Deforestation and degradation of forest reserves.	Oil pollution and pollution from salty water from artificial canals constructed by Chevron oil company.	Oil pollution and contamination of drinking water from oil production activities of multinational oil companies.	Oil pollution and contamination of drinking water from oil production activities of multinational oil companies.
Number of people that participated in the focus group.	15	12	10	10	9
Number of health professionals interviewed	None	None	2	4	1
Environmentalist interview Member of NCF, staff of forest reserves and other environmental agencies	2	4	3	2	2

Age range of respondents	25-55 years	25-55 years	25-55 years	25-55 years	25-55 years
Nature of group	Natural group: all participants were matured men and women who have better knowledge about environmental changes.	Natural group: all participants were matured men and women who have better knowledge about environmental changes.	Natural group: all participants were matured men and women who have better knowledge about environmental changes.	Natural group: all participants were matured men and women who have better knowledge about environmental changes.	Natural group: all participants were matured men and women who have better knowledge about environmental changes.

The focus group discussion was carried out with five to fifteen adult men and women of ages 25-55 years in each case. Table 4.23 shows a description of the composition of one-to-one interview and focus group discussions. The focus group consisted of natural group of matured men and women participants, who have good knowledge about environmental changes in their environment. At the beginning of the focus group discussion, the participants were engaged in map observation, in order to draw their attention to the environmental change issues to discuss. The maps depict various environmental changes around them as resulted from remote sensing analysis.

4.2.7. Research Ethics

Understanding how research influences all those that are involved in it, has become a great concern in recent years (e.g. Symon and Cassell 2012). As a result, application for ethical approval was made to the King's College Research Ethics Panel. The methods and approaches used in this study took into consideration all the ethical issues highlighted by King's College Research Ethics Panel, and the form is in Appendix A.

The ethical issues addressed for the social research work were: Individual and data privacy; confidentiality; and respondents' comfortability with the questions. All these were first explained and made clear to the people interviewed, and the participants of the focus group discussions. After their agreement to participate in the research, an information sheet and a consent form were given to them to fill and return.

The information sheet shows that the participant is not under any obligation, but could participate if he wants to; and choosing not to take part will not disadvantage him in any way. Besides, the participants were asked at the beginning, if they will like their anonymity to be protected. This was done because Bryman and Bell (2007) have earlier noted that although guarding the anonymity of respondents is known to be part of research ethics, there might be some cases where the respondents might not want to be anonymous, they may wish to be known because making them known might be a vital approach of retaining the owners of their stories. Likewise, the information sheet also states some important information about the research so that the participants would understand why the research is being done and what their participation will involve, before they decide whether they want to take part or not. The consent letter and information sheet are vital to this research, as they give the respondents the opportunity to understand the purpose of the research more and to make a decision whether to be part of the research or not. The participants were given twenty minutes to read the information sheet (Appendix B) carefully, discuss it with others if they wished, ask questions if any part of the information was not clear to them, and consent forms (Appendix C) were filled and signed by all participants.

CHAPTER FIVE
RESULTS

This chapter presents the results of landuse change, drivers of change, and their societal implications on the Niger Delta of Nigeria. The results are discussed under two main sections. The first section discusses the results from remote sensing analysis, which demonstrate the results from both classification and non-classification assessment of landuse change in the Delta. The results from social research are presented in the second section and illustrate the relationship between the changes detected by the remote sensing analysis, and their environmental and societal impacts on the Niger Delta.

5.1. Remote Sensing Results

The remote sensing results are presented in two sub-sections: overall changes in the entire Niger Delta; and then specific case studies. Thus, the first sub-sections presents the results of classification and post-classification change detection; showing the overall rate and trend of landuse change for the entire Niger Delta using three dates: 1987, 2001 and 2011. The NDVI results showing the patterns and intensity of forest degradation in entire Niger Delta are also presented. The second part of the section concentrates on the results of spatial-temporal changes using more than threedate datasets: between 1984 and 2011 in different forest types of the Delta, concentrating on three major case studies:

(a) Urban expansion in Okitipupa, Warri, Port Harcourt and Benin,

(b) Deforestation in Okomu, Gili-Gilli, Osomari, Taylor creek, and Bayelsa National Parks, as well as Sambrero, Egbedi, Uwet Odot and Umon Ndealichi forest reserves.

(c) Impacts of oil exploration and production activities on Tsekelewu.

Assessing landuse change based on the destruction and degradation of different forest types (as discussed in chapter two in the Delta), is important because they have different biodiversity. For example, lowland rainforest is characterized by the dwarf antelope and Sclater’s guenon, while freshwater swamp is principally the home of white-throated guenon and the pygmy hippopotamus (if it is not yet extinct), and mangrove is characterised by mona monkey and the sitatunga (Blench 2007). Spatial and temporal differences in the rate of landuse change within lowland rainforest, freshwater swamp and mangrove are also presented in this chapter.

5.1.1. General Assessment of Landuse Change in the Entire Niger Delta

Tables 5.1 and 5.2 summarise spatial distribution of landuse and percentage change, while Figures 5.1, 5.2 and 5.3 illustrate spatial and temporal changes in different forest types of the Niger Delta. The results from classification analysis reveal three major environmental changes in the entire Niger Delta, over the study period. The rates of urban and farmland expansion have increased, while severe deforestation can be seen for lowland rainforest, with slower rates for freshwater swamp and mangrove forests (Table 5.1 and Figure 5.2). From Figure 5.1, it is clear that the extent of landuse change varies from one region of the Delta to another, and the south-eastern part of the Delta has experienced a higher rate of change when compared to other regions. Bare ground reduces from 1987 to 2011 (Tables 5.1 and 5.2). High extent of bare ground observed in 1987 appears to be following the rapid destruction of mangrove around Tsekelewu in the 1980s. The causes and implications of changes in bare ground are fully discussed in Section 5.7, under the case studies.

5.1.1.1 Deforestation

As noted above, there is greater deforestation within lowland rainforest (Table 5.1 and Figure 5.2B) compared to other forest types. In 1987, the area covered was 21,481km^2, but this was reduced to 16,537 km^2 in 2001 and 13,157 km^2 in 2011 (Table 5.1). Thus, approximately 39% lowland rainforest have been lost during the past three decades (Table 5.2). The extent of deforestation is very high compared to freshwater swamp forest (14.6%), and mangrove (15.4%) as obvious in Table 5.2. Looking at the landuse change in the other classes, two major factors appear to be responsible for this. Firstly, the rate of urban expansion has increased over the years, particularly in the lowland rainforest areas (Figures 5.1 and 5.2B), where the number of urban settlements and the rate of their expansion were higher than the other forest types (Figure 5.1). As noted in chapter two, the preferential concentration of settlements in lowland rainforest is due to the fact that the part of the Delta is the only dry part with no perennial flooding, and thus is good for farmland and construction of buildings. As a result, this encourages farming activities and expansion of settlement to accommodate the rapidly increasing population.

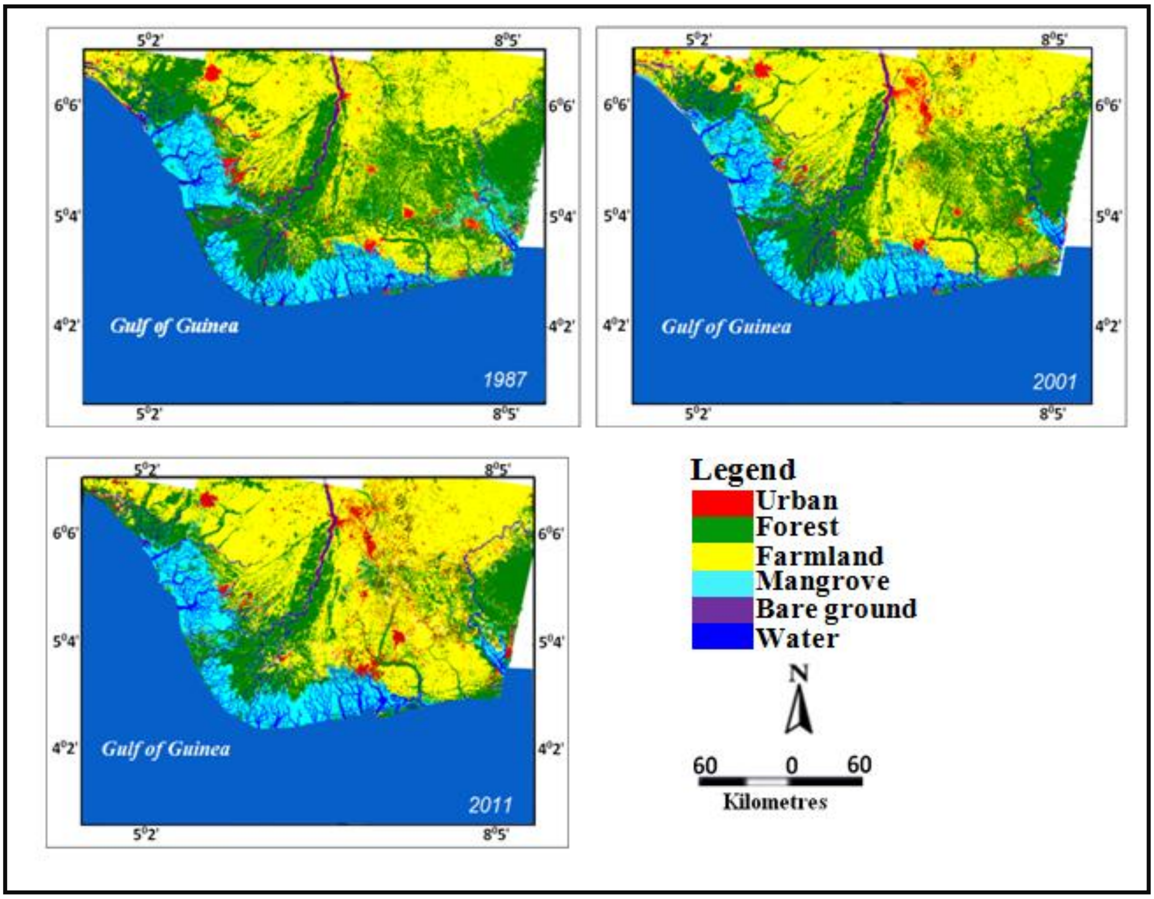


Figure 5.1. Maps of spatial and temporal change in landuse of the Niger Delta.

Table 5.1. Area of landuse change in the Niger Delta between 1987 and 2011

Landuse Classes	1987 (km^2)	2001 (km^2)	2011 (km^2)
Lowland rainforest	21481	16537	13157
Freshwater forest	9734	8855	8310
Mangrove forest	9965	9255	8430
Urban	3428	4894	6326
Farmland	37426	42436	45874
Water	2450	2671	2582
Bare ground	354	190	159

Table 5.2. Landuse change in the Niger Delta between 1987 and 2011

Land Use Class	Total Change 1987-2001		Total Change 2001-2011		Overall Change 1987-2011	
	km^2	%	km^2	%	km^2	%
Lowland rainforest	-4944	-23.0	-3380	-20.4	-8324	-38.8
Freshwater forest	-879	-9.0	-545	-6.2	-1424	-14.6
Mangrove forest	-710	-7.1	-825	-8.9	-1535	-15.4
Urban	1466	42.8	1432	29.3	2898	84.5
Farmland	5010	13.4	3438	8.1	8448	22.6
Water	221	9.0	-89	-3.3	132	5.4
Bare ground	-164	-46.3	-31	-16.3	-195	-55.1

Figure 5.3 shows the implications of urban and farmland expansion in the different forest types for comparison purposes. In general, the least deforestation is observed in the freshwater forest area of the Delta. In 1987 for example, the area covered by the freshwater swamp forest was 9734 km^2, but this declined to 8855 km^2 in 2001, and 8310 km^2 in 2011 (Table 5.1 and Figure 5.2C), with an overall total loss of about 1424 km^2 (Table 5.2). The reason for low rate of deforestation in this forest might be due to the fact that freshwater swamp forest is covered in a dense river network (Figure 5.2), and inundated by annual Delta flooding, which permits little urban expansion and prevents agricultural activities.

The extent of mangrove deforestation is slightly higher than that of freshwater swamp forest (Figures 5.2 and 5.3). Over the period of study, the mangrove declined from 9965km^2 in 1987 to 9255km^2 in 2001, then to 8430km^2 in 2011 (Table 5.1). The overall area lost in mangrove is roughly 1535 km^2 between 1987 and 2011, which is 1.20% higher than that of freshwater swamp (Table 5.2). It has been reported also in the previous literature that there is a continuous removal of mangrove in the region (Godstime *et.al*. 2007; Salami *et.al*. 2010; Mmom and Arokoyu 2010). Between 1970 and 1989 for example, Adegbehin and Nwaigbo (1990) noted that over 200,000 poles and wooden items such as logs or billets have been extracted from the Niger Delta. Our result is in line with this report of Adegbehin and Nwaigbo (1990) in such that nearly 9000 km^2 has been deforested between 1987 and 2011, and the remaining forest has been severely degraded. The highest deforestation is obvious in the lowland rainforest, in which almost 40% of forested areas have been destroyed, leading to almost complete absence of primary forests (Uyigue and Agho 2007). The results from the present study therefore, support this view.

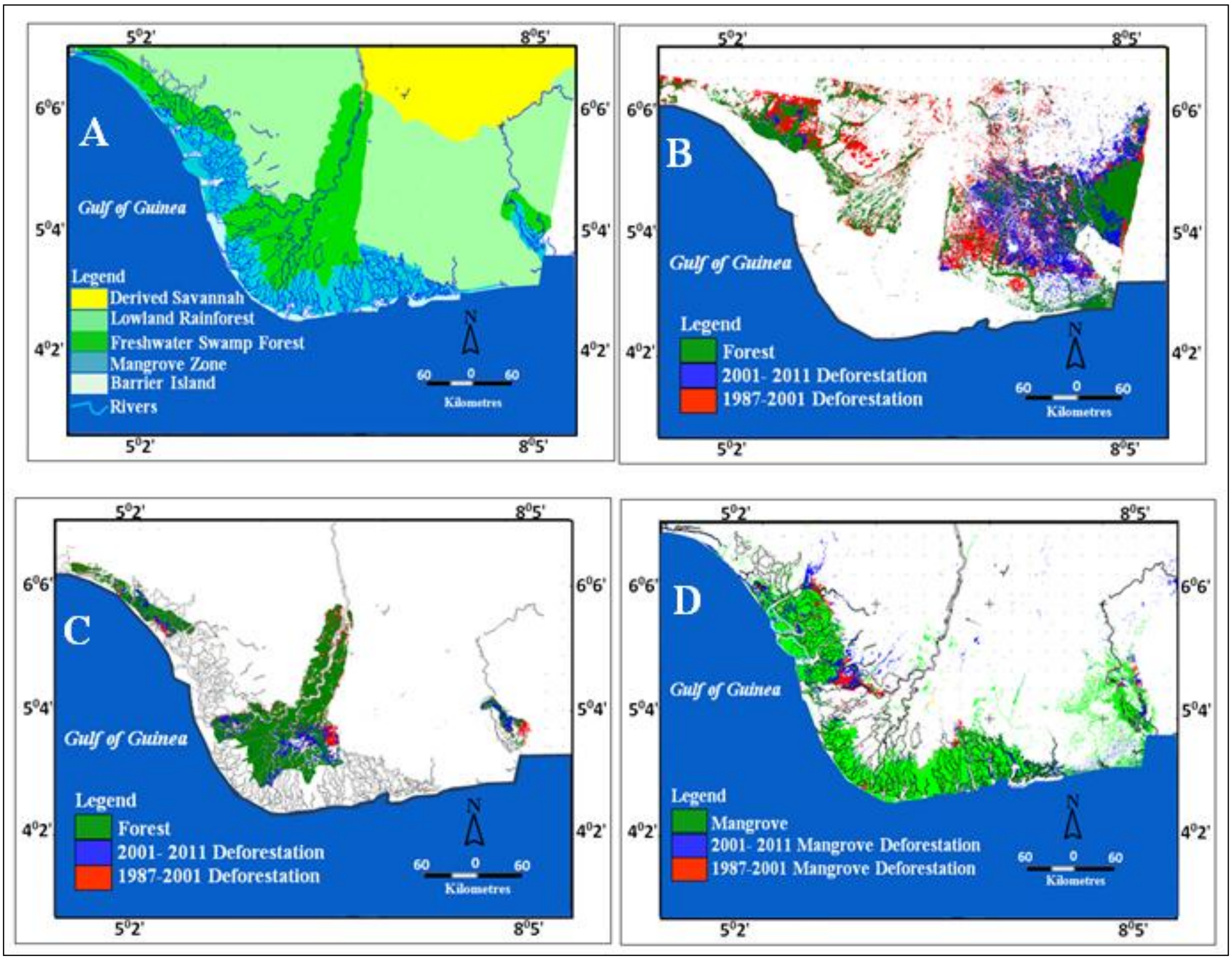


Figure 5.2. Maps showing deforestation within different forest types in the Niger Delta

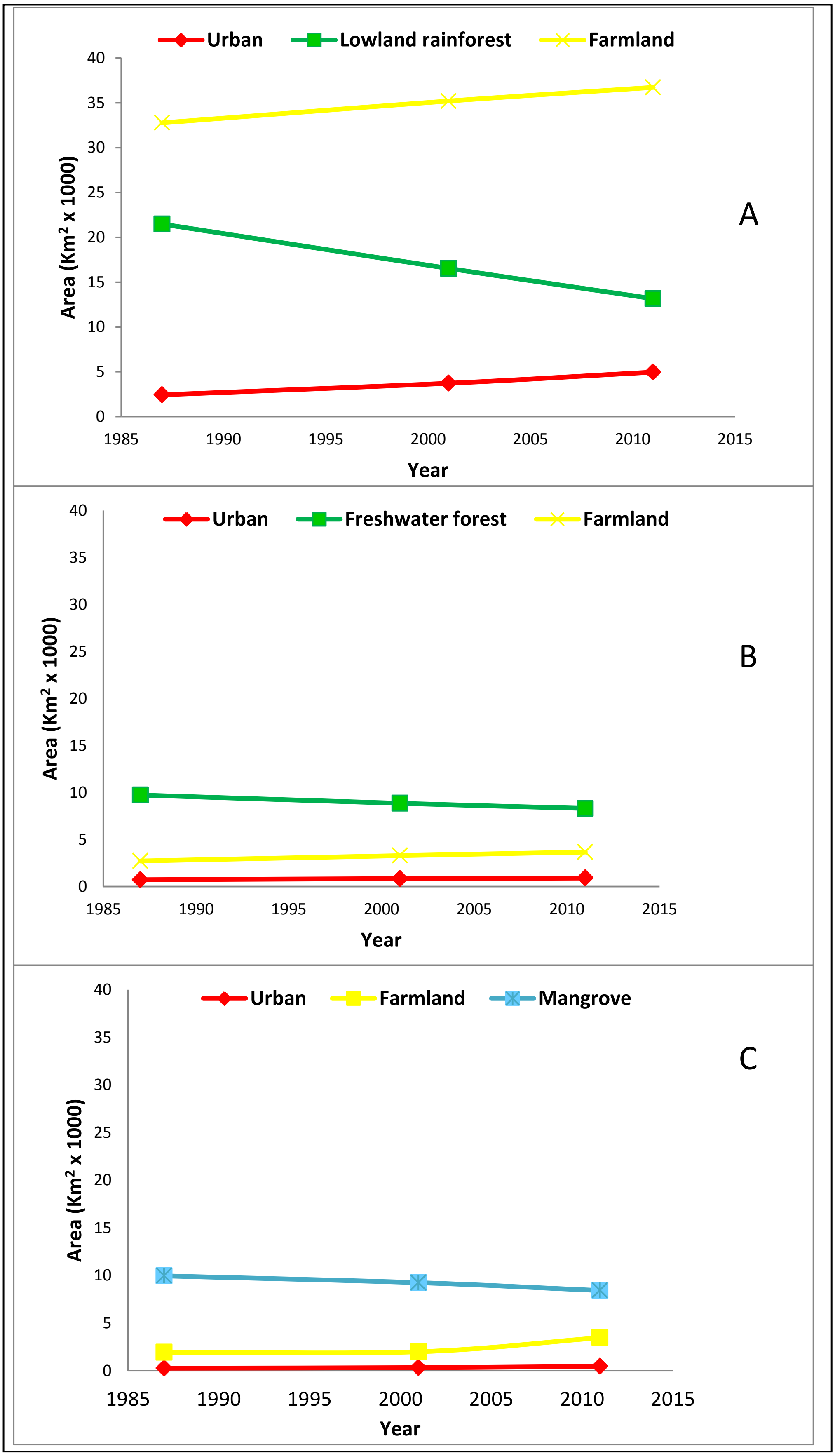


Figure 5.3. Temporal changes in landuse within different forest types in the Niger Delta.

Another way to evaluate deforestation rate is to consider the annual rate. Table 5.2a summarizes the annual rate of deforestation in different forest types. As expected, deforestation is higher for lowland rainforest than for the other classes, but varies slightly, appearing higher, during the 1980s and 2000s (0.6% and 0.7%), compared to 0.5% in the 1990s (Table 5.2a and Figure 5.3). The reason for this decadal variation is not absolutely clear, though accessibility to forest through construction of road networks in 1984 and 2000s might account for this (See Section 5.2.1). Mangrove reduces greatly during 1980s, compared to the other years (Table 5.2a). This appears to be due to the rapid destruction of mangrove around Tsekelewu in the 1980s because of oil production. This is fully discussed in Section 5.7, under case studies.

Table 5.2a. Annual rate of landuse change in the Niger Delta

Landuse Class	1984-1987 Annual % Change	1987-2001 Annual % Change	2001-2011 Annual % Change
Lowland Rainforest	-0.60	-0.50	-0.70
Freshwater Forest	-0.20	-0.11	-0.11
Mangrove	-2.90	-0.20	-0.70
Urban	1.90	2.80	1.90
Farmland	3.20	2.60	2.40

Figure 5.4 shows the location and timing of deforestation in the Delta, and its relationships with forest reserves and National parks. One important observation is that deforestation is found in all parts of the Delta, but four principal areas of intensive deforestation are noted: (1) Cross River (2) Port Harcourt (3) Okomu and (4) Warri (Figure 5.4). Overall, these results imply that there are, and have been spatial and temporal variations, not only in the rate of deforestation, but also in the regional intensity of the deforestation, with a marked difference in deforestation rates, within the different forest types of the Delta. The majority of forest reserves and national parks in lowland rainforest have been severely deforested, contributing

to the general downward trend in forest in the Delta, while those in freshwater swamp and mangrove experience less deforestation pressure.

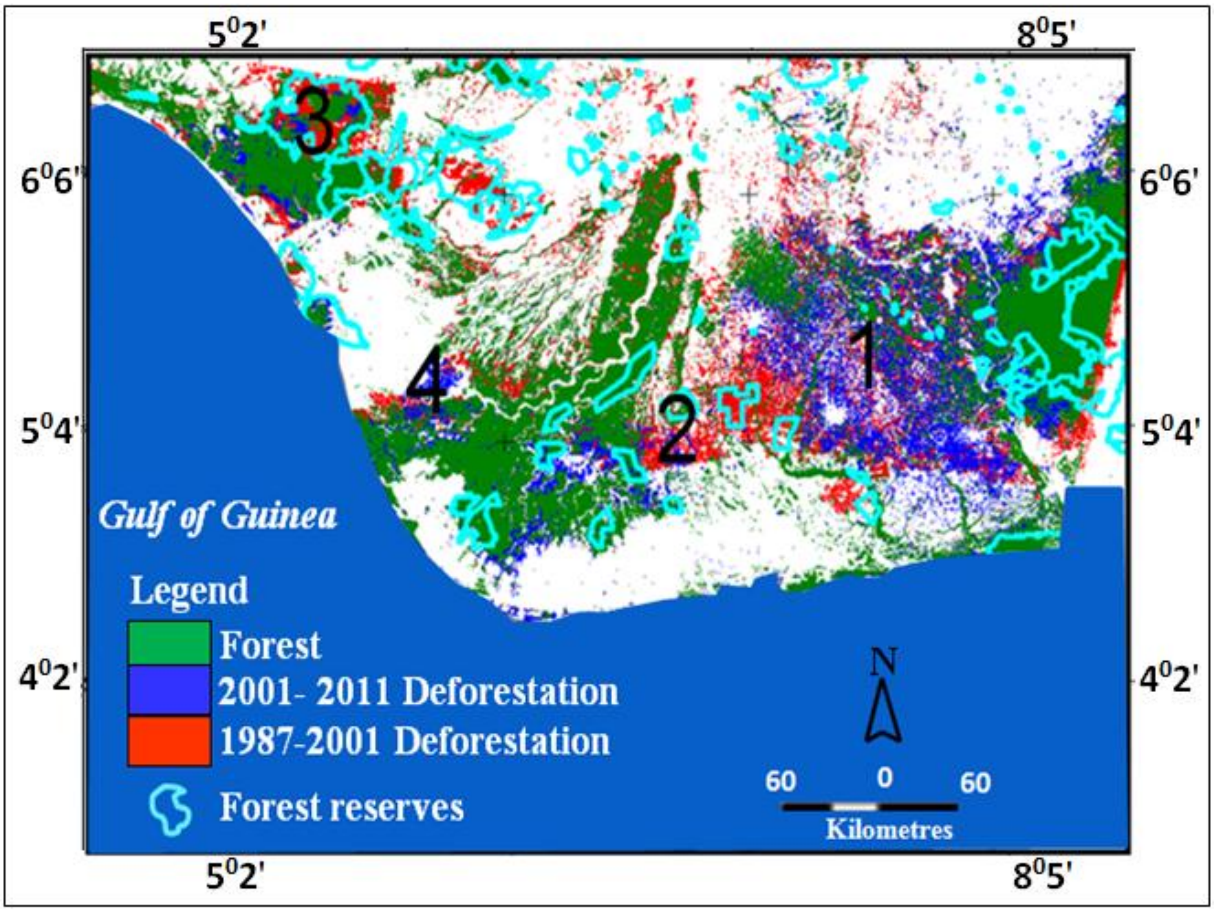


Figure 5.4. Deforestation along the major forest reserves and national parks in the Delta

5.1.1.2 Urbanisation

A major factor driving landuse change in the Delta appears to be the expansion of urban areas (Figures 5.1 and 5.2D), which has nearly doubled between 1987 and 2011 (Table 5.1). In 1987, urban class was about 3428km^2, but by 2011, it has increased to 6326km^2 (Table 5.1). Four major locations of urban expansion can be seen in the Niger Delta over the period: (1) Port Harcourt (2) Warri (3) Benin City and (4) Onitsha area (Figure 5.5). It was evident in chapter two that these cities contained the highest population in the Delta according to the population census data of 2006. Table 5.2 shows the annual rate of change over the period between 1987 and 2011. In this case, the annual rate of urban expansion is highest in 1990s (with 2.8%), compared to 1980s and 2000s (Table 5.2). The reasons for this variability in urban growth rate are not clear.

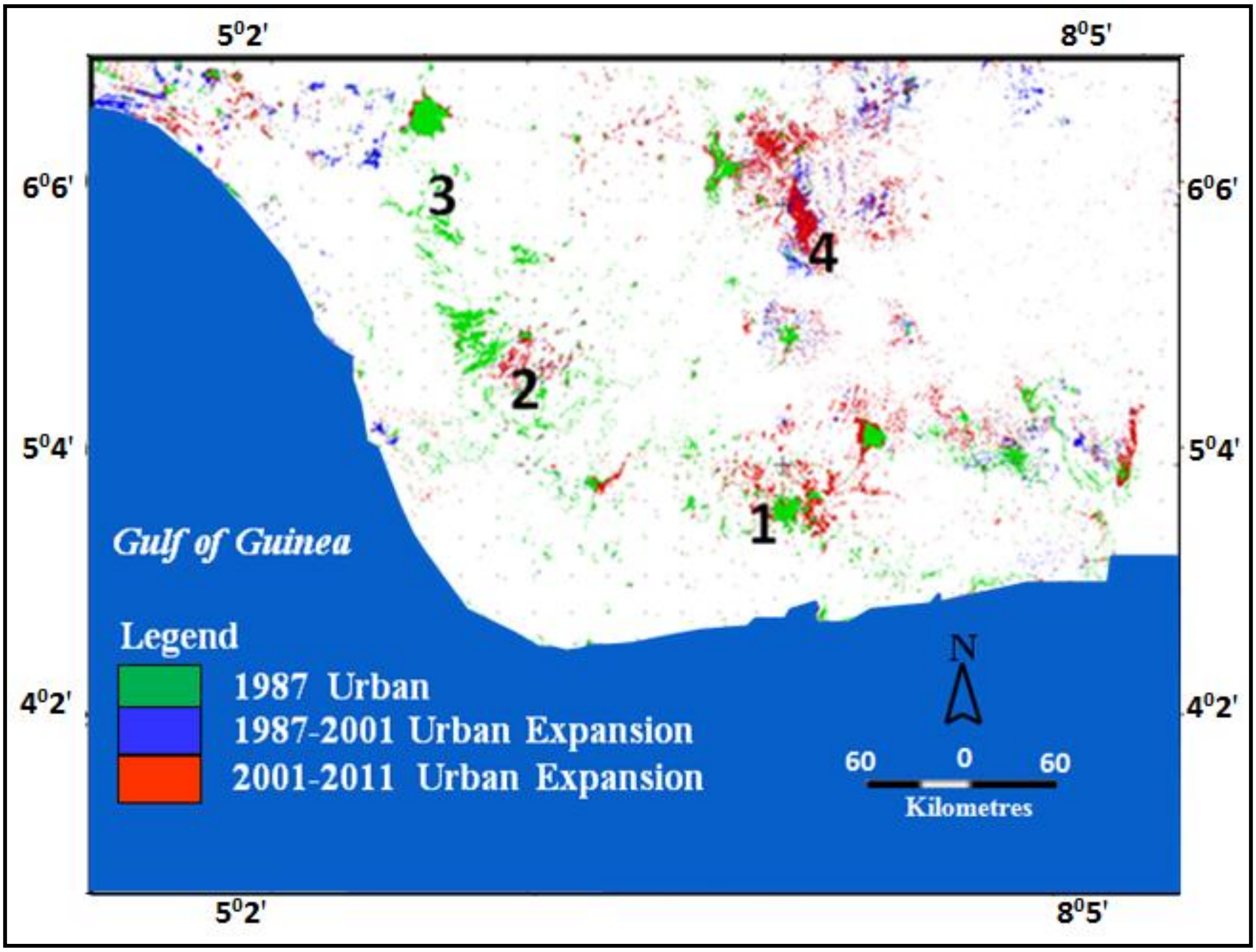


Figure 5.5. Urban expansion over the period between 1987 and 2011

The rate of urban expansion appears to be concentrated within the lowland forest, when compared to other forest types (Figure 5.2). The urban area expands by 2536km^2 between 1987 and 2011 in the lowland rainforest, thus expanding by almost 50% over the period (Table 5.1 and Figure 5.3). On the other hand, little urban expansion was noted in regions of freshwater swamp and mangrove, with the urban area expanding by 176km^2 (approximately 16%), and 185km^2 (approximately 38%), between 1987 and 2011 for freshwater swamp forest and mangrove respectively (Figure 5.3). The high rate of urban settlement in the lowland rainforest clearly contrasts with other forest types and might be due to the fact that the rainforest region is good for construction of buildings, being the driest part of the Delta, with no seasonal flooding (Ebeku 2006).

5.1.1.3 Farmland Expansion

Another major driver of landuse change in the Delta is the expansion of farmland. Maps of farmland reveal considerable changes during the study period. The area covered by farmland increases by 8448km^2 (22.6 %) between 1987 and 2011 (Table 5.1). From Figure 5.6, it is shown that there are two major regions of farmland extension in the Niger Delta: (1) the Eastern part of the Delta in Cross Rivers State and (2) the Western part of the Delta in the vicinity of Benin City in Edo state. Significant farmland expansion is also observed in and around forest reserves and national parks (Figure 5.7). For example, a high rate of farmland expansion is evident in the East-central of the Delta, where there is little forest left in the forest reserves. Even though, farmland increases over the periods of study, the intra-annual rate of change declines from 3.2% during 1980s, to 2.6% during the 1990s, and then to 2.4% during 2000s (see Table 5.2). The reason for this decline in farmland expansion might be due to lack of good farming land remaining.

The extent of farmland expansion is greater in the lowland rainforest, compared with the other types of forest (Figure 5.6). Farmland within lowland rainforest was 32769km^2 in 1987, but increased to 35204km^2 in 2001, and then to 36730km^2 in 2011 (Figure 5.3). This is because the lowland rainforest has well-drained soil suitable for agricultural activities. In contrast, about 500km^2 and 443km^2 of forest have been lost to farmland expansion in the freshwater swamp and mangrove respectively, between 2001 and 2011 (Figure 5.3). The reason for low rate of farmland expansion in freshwater swamp and mangrove, compared to lowland rainforest, might be due to the fact that the two forest types are on sit of waterlogged soils, and are commonly inundated by annual flooding, which permits little agricultural activities. The results imply that patterns of landuse change; rate of farmland expansion; and forest loss observed in the Niger Delta are best explained in terms of different forest types.

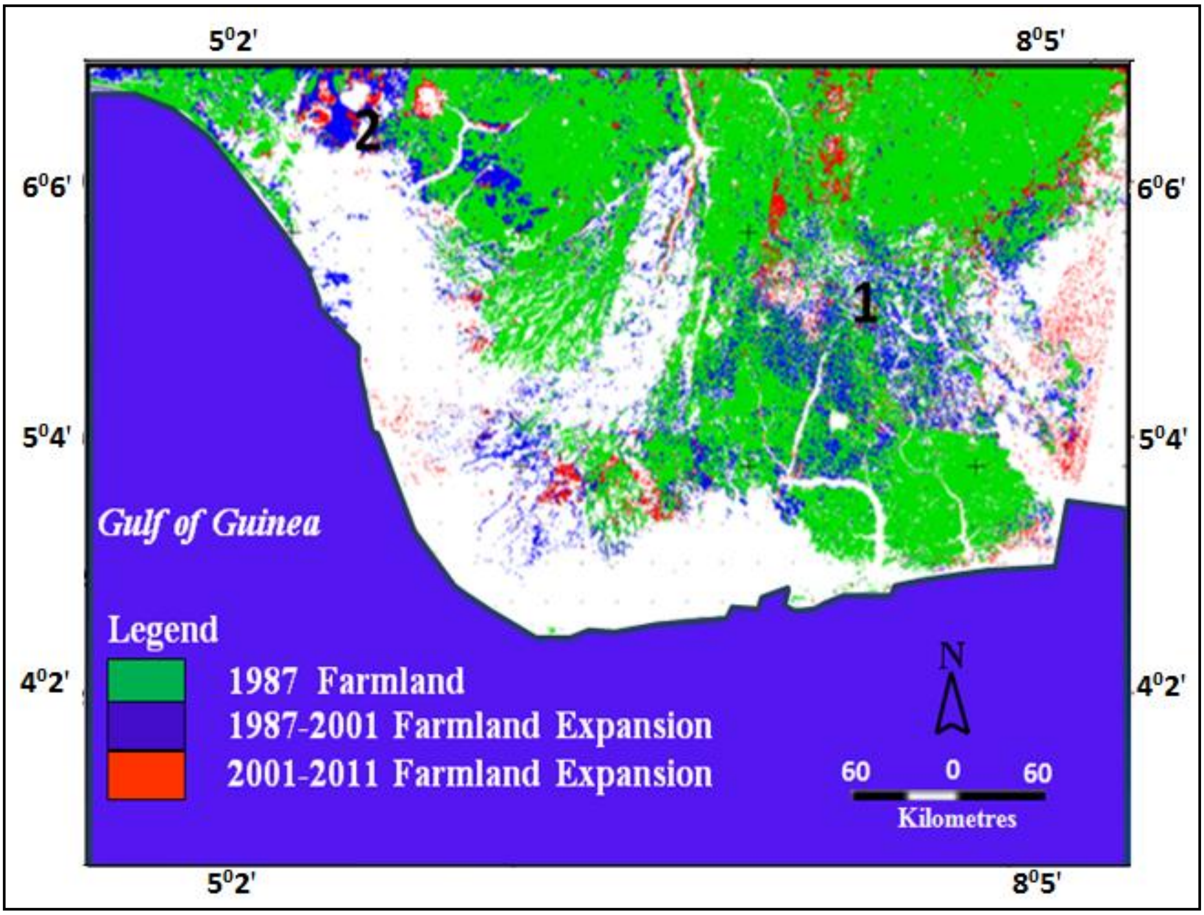


Figure 5.6. Farmland expansion over the period between 1987 and 2011

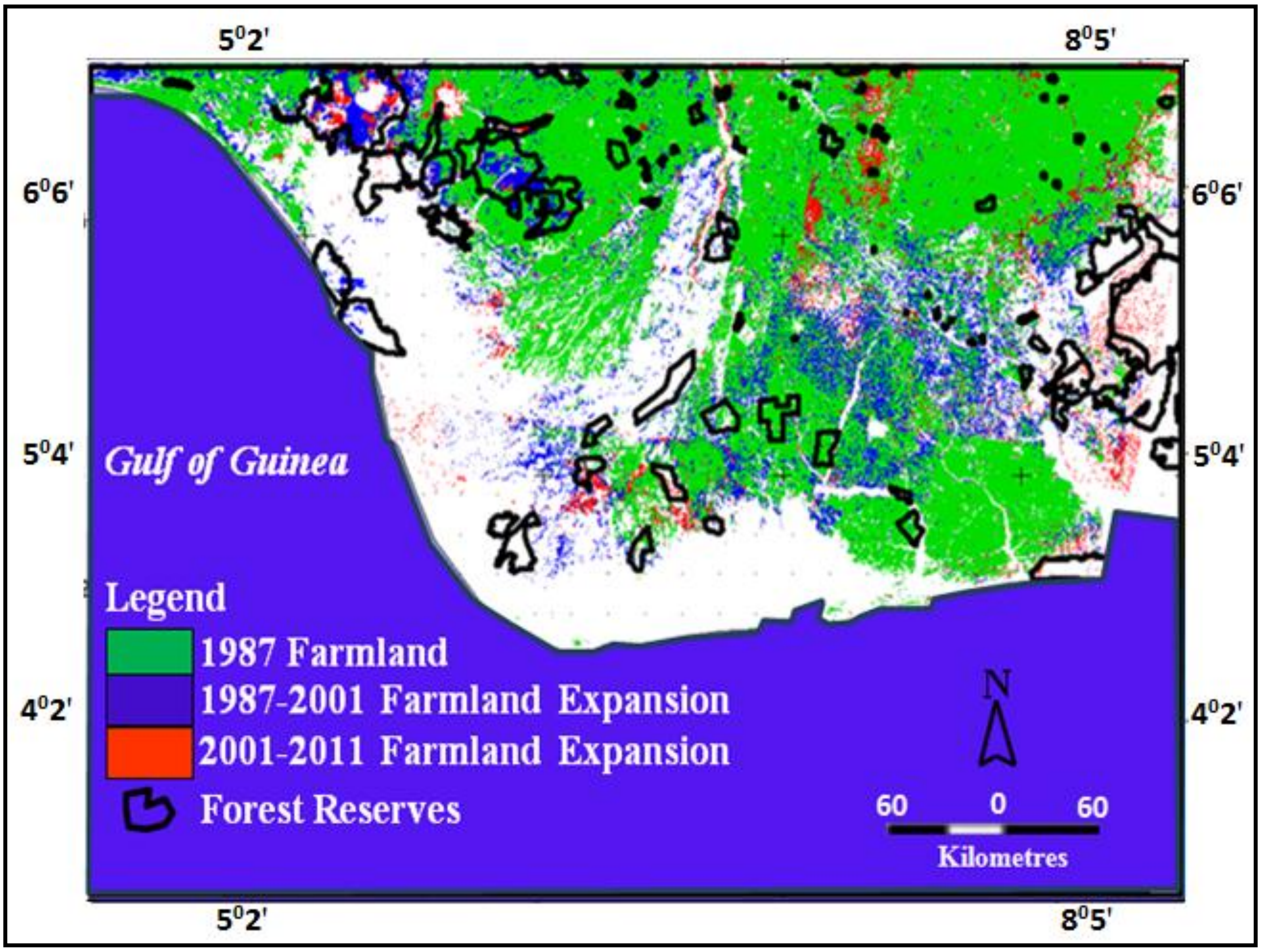


Figure 5.7. Farmland expansion with forest reserves in the Delta overlain

5.1.2. Vegetation Degradation in the Entire Niger Delta

Classification methods cannot provide accurate appraisal of vegetation degradation. It is effective in assessing landuse change, but gradual reduction in the vegetation in forests, resulting from factors such as selective logging, may not be captured by classification methods. Therefore, NDVI were used to evaluate vegetation degradation.

The statistics of NDVI analysis for the forested area over the period of study are presented in Table 5.3, while Figure 5.8 illustrates the rate of vegetation degradation in forests for the entire Niger Delta. To obtain NDVI values for forests only, the region which has been mapped as forest in the classification, was used as a mask to exclude the NDVI of other landuse classes. The results show that forest vegetation in the Delta has been under pressure. Areas of major degradation are shown in a light green/white colour in the NDVI coloured maps (Figure 5.8). The NDVI results show that several regions of forests are mostly degraded, especially in Northwestern and North-eastern part of the map labelled 2011 (Figure 5.8). The mean value of NDVI decreases from 0.61 in 1987, to 0.55 in 2001, and decreases further to 0.48 in 2011 (Table 5.3 and Figure 5.9). These values imply that the rate of degradation during 2001 and 2011 is increasing.

Table 5.3. The NDVI statistics in the Niger Delta between 1987 and 2011

Image Date	Min	Max	Mean	St.dev.
1987	0.46	0.89	0.61	0.16
2001	0.42	0.66	0.55	0.15
2011	0.37	0.66	0.48	0.13

What is clear from these results is that degradation is going on, in all types of forest, but the most degraded area is the lowland rainforest (Table 5.4). The NDVI results moreover, reveal that the rate of forest degradation, in the regions of lowland rainforest (Figure 5.10) that are left, is more intense compared to freshwater swamp forest (Figure 5.11) and mangroves (Table 5.4 and Figure 5.12).

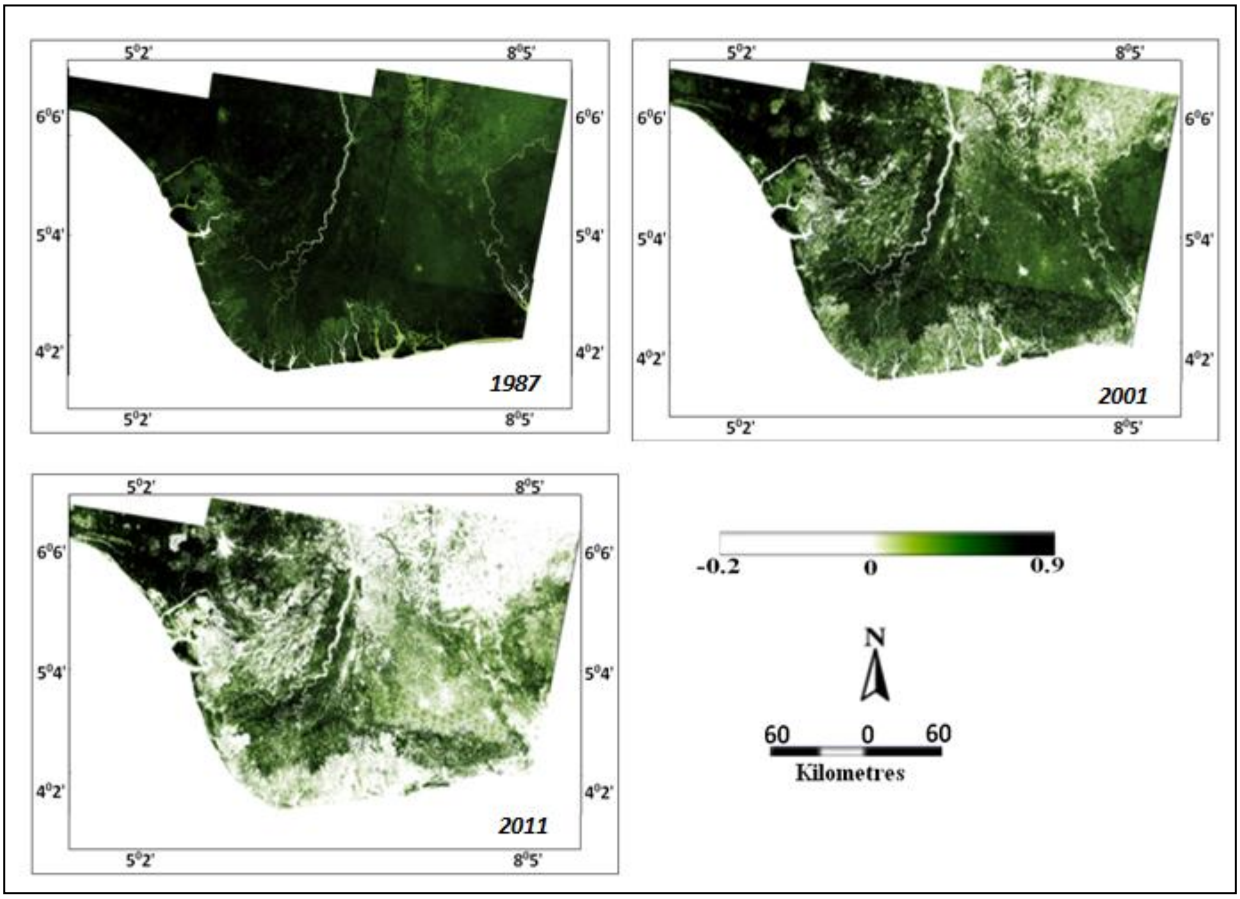


Figure 5.8. NDVI maps showing forest degradation in the Niger Delta from 1987 to 2011

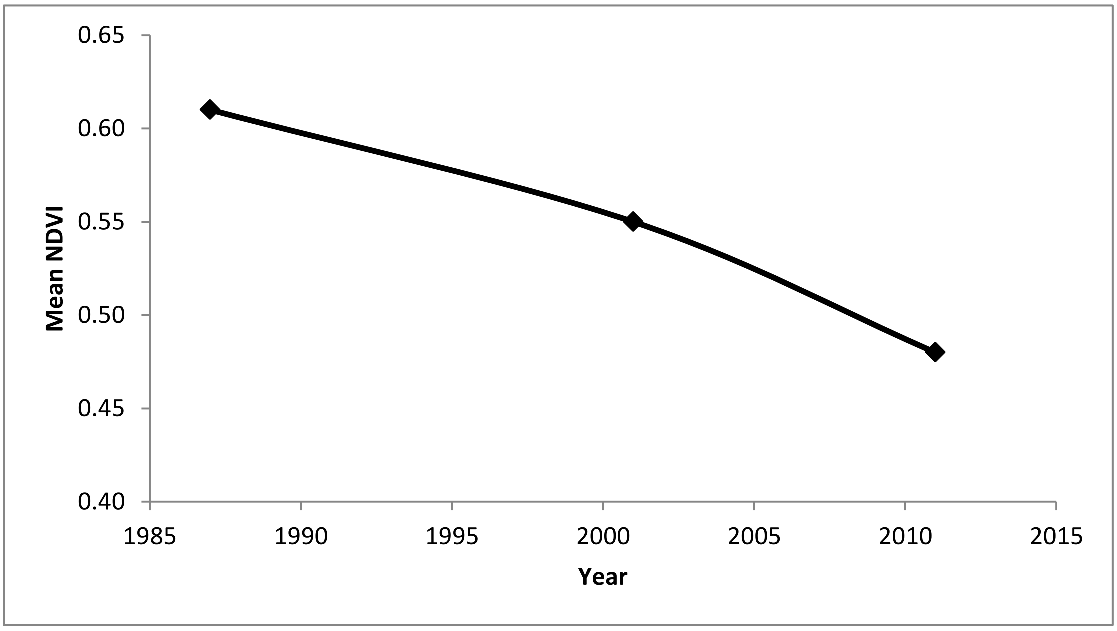


Figure 5.9. Changes in the mean NDVI for the entire Niger Delta, from 1987 to 2011

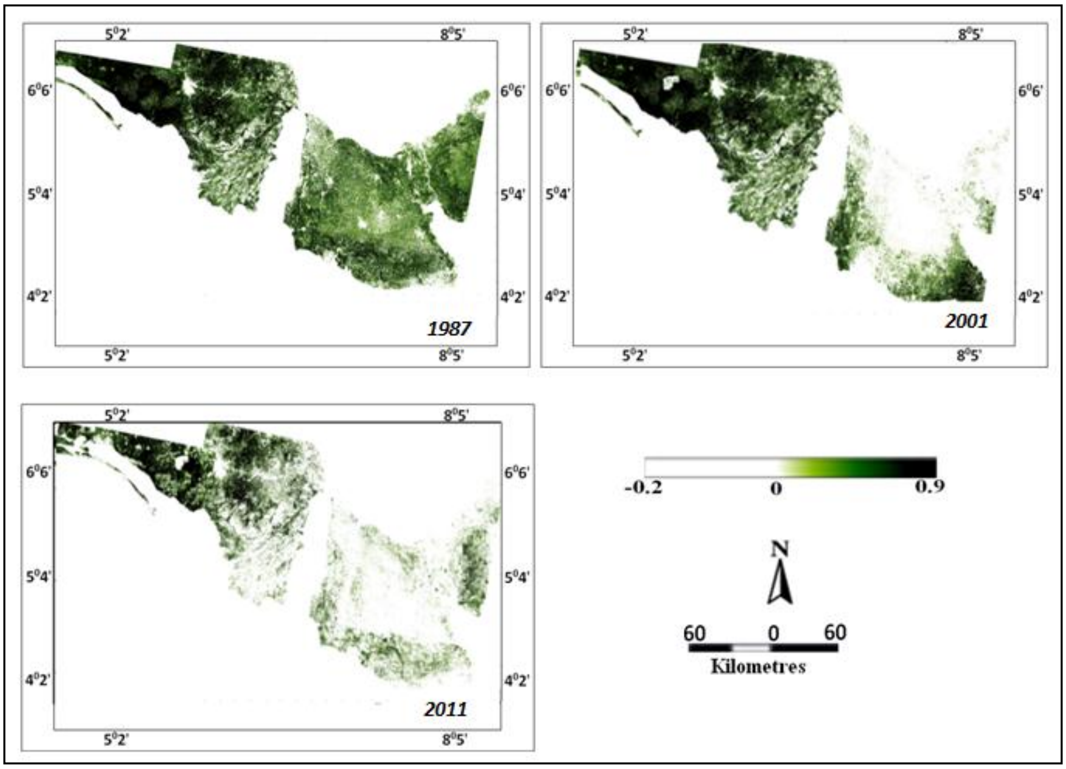


Figure 5.10. NDVI maps showing forest degradation in the lowland rainforest of the Niger Delta from 1987 to 2011

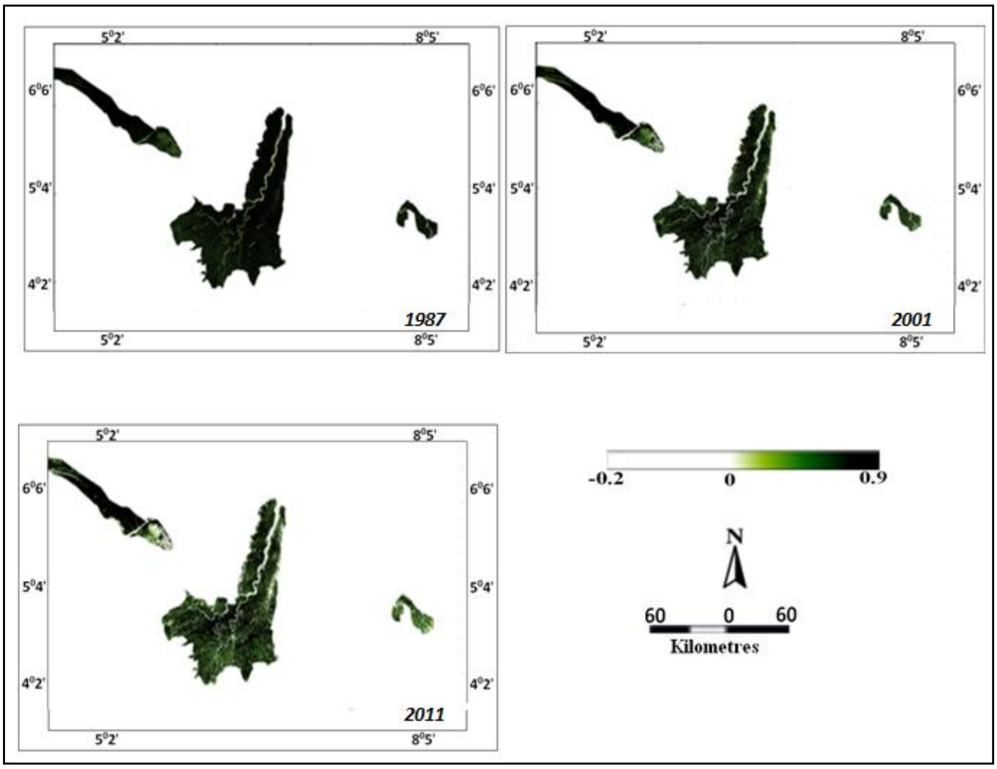


Figure 5.11. NDVI maps showing forest degradation in the freshwater swamp forest of the Niger Delta from 1987 to 2011.

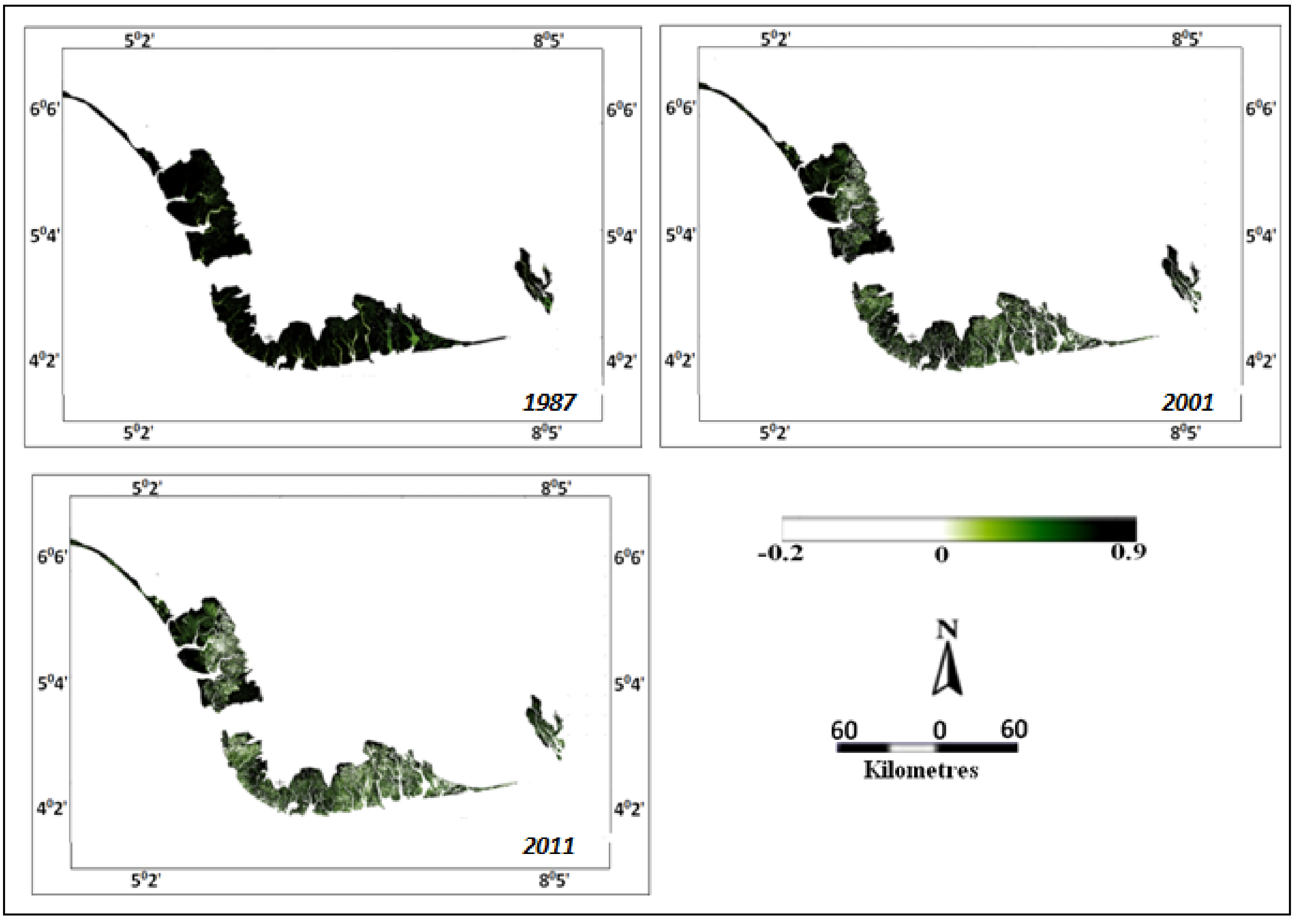


Figure 5.12. NDVI maps showing forest degradation in the mangrove forest of the Niger Delta from 1987 to 2011

Table 5.4. The mean NDVI for different forest types in the Niger Delta, from 1987 to 2011

Ecological Forest Type	1987	2001	2011
Lowland Rainforest	0.61	0.56	0.45
Freshwater Swamp Forest	0.78	0.66	0.62
Mangrove Forest	0.45	0.42	0.38

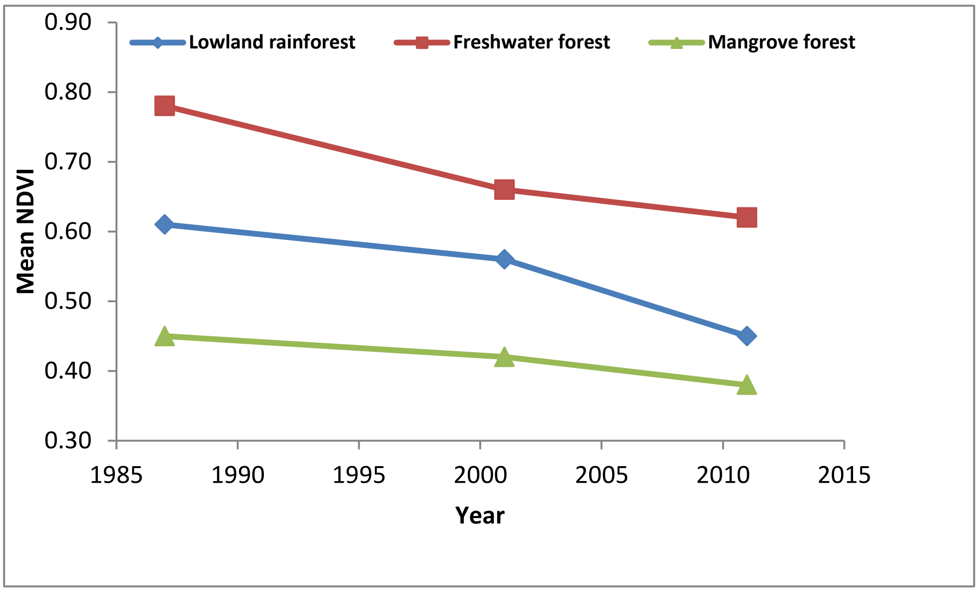


Figure 5.13. Changes in the mean NDVI for different forest types in the Niger Delta, from 1987 to 2011

Though, the classification results illustrate that freshwater swamp has not been heavily deforested, there appears to be high rate of removal of trees in the forest in recent years, as shown in the NDVI. Classification results also showed that mangrove is being deforested at a slower rate than the other types of forest. Despite the low rate of mangrove deforestation, the results from NDVI still showed that this forest type is being degraded.

5.1.2.1. Changes within the Protected Areas in the Niger Delta

To assess the forest loss and degradation in the protected areas of the Delta, the classification results were combined with those of the NDVI within the protected regions, as defined by the vector file of forest reserves and national parks. This assessment is done to determine how deforested and degraded each one is, and to rank them in terms of the total amount of forest they have remaining (Table 5.5). It is evident from the same table (Table 5.5), that the majority of the forest reserves and national parks have lost over 50% of the area in lowland rainforest, which is evident inUte-Ukpu, Nsukwai and Ogwashi-Uku, which have lost over 99%. The rate of deforestation is much lower in reserves located in freshwater swamp and mangrove (Figures 5.4 and 5.14). The highly deforested reserves tend to be the ones located close to the major roads. For example, Apoi creek and Ikebiri creek lost just 0.1% because they are both not accessible, but Sapoba and Sambrero lost over 90% due to the fact that they are located close to the major roads (Table 5.5). Despite the variations in the deforestation observed in these forest types, the rate of degradation is quite similar and high for reserves in both lowland rainforest and freshwater swamp, but mangrove has a lower degradation rate.

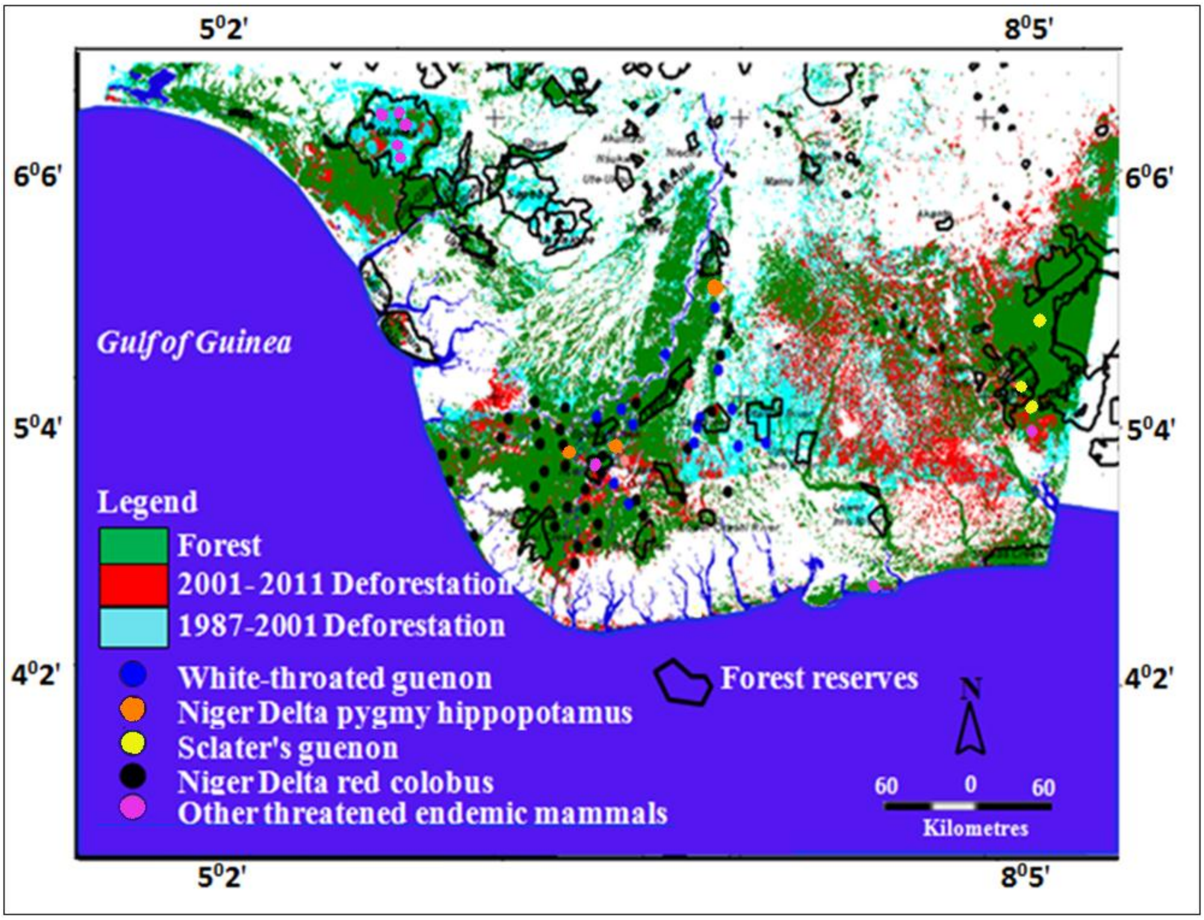


Figure 5.14. Relationship between change in forest and location of endangered and threatened endemic animals within forest reserves and national parks of the Niger Delta.

Table 5.5. Rate of deforestation, forest remaining and variations in NDVI for forest reserves and national parks in different forest types in the Delta

Forest type	Forest reserve	Total protected AREA	Forest left (km^2)	Forest lost (km^2)	% of Forest lost	NDVI 1987	NDVI 2001	NDVI 2011	Diff. NDVI 1987-2011
Lowland rainforest	Okomu	1123.60	344.90	778.71	69.31	0.98	0.64	0.41	-0.57
	Gilli-Gilli	311.91	287.60	24.30	7.80	0.96	0.88	0.85	-0.11
	Stubbs Creek	295.80	267.10	28.70	9.70	0.79	0.77	0.72	-0.07
	Ukpe-Sobo	159.23	139.10	20.10	12.60	0.49	0.43	0.38	-0.11
	Ekenwan	212.40	114.90	97.50	45.90	0.81	0.61	0.54	-0.27
	Umon Ndealichi	92.90	81.20	11.70	12.61	0.53	0.34	0.28	-0.25
	Ebue	95.40	71.10	24.31	25.52	0.87	0.56	0.32	-0.55
	Ologbo	182.50	66.80	115.71	63.41	0.75	0.62	0.59	-0.16
	Obaretin	1120.00	59.00	53.01	47.31	0.45	0.22	0.15	-0.3
	Sapoba	526.90	46.40	480.53	91.21	0.51	0.32	0.28	-0.23
	Sambrero	137.60	43.90	93.70	68.10	0.53	0.31	0.25	-0.28
	Upper Imo River	101.21	30.60	70.60	69.80	0.81	0.53	0.26	-0.55
	Mamu River	52.90	27.10	25.80	48.81	0.65	0.36	0.28	-0.37
	Lower Imo River	77.10	21.50	55.61	72.1	0.59	0.31	0.19	-0.4
	Usonigbe	326.40	11.40	315.0	96.5	0.65	0.35	0.26	-0.39
	Isheagu	13.90	7.60	6.31	45.3	0.64	0.21	0.18	-0.46
	Lower Enyong	25.60	3.60	22.01	85.9	0.58	0.39	0.17	-0.41
	Niocha	250	0.50	24.50	98.0	0.31	0.21	0.1	-0.2
	Oji River	3.10	0.404	2.70	87.1	0.25	0.14	0.08	-0.17
	Ute-Ukpu	61.71	0.103	61.60	99.8	0.31	0.19	0.09	-0.22
	Nsukwai	15.30	0.002	15.30	100.0	0.18	0.09	0.05	-0.13

	Ogwashi-Uku	23.50	0.005	23.50	100.0	0.16	0.05	0.03	-0.13
Freshwater swamp forest	Taylor Creek	217.60	206.30	11.32	5.2	0.65	0.52	0.49	-0.16
	Apoi Creek	187.60	187.50	0.11	0.1	0.75	0.64	0.48	-0.27
	Osomari	137.20	83.60	53.60	39.1	0.49	0.43	0.39	-0.1
	Nun River	92.90	78.80	14.10	15.2	0.55	0.31	0.29	-0.26
	Edumanom	88.30	71.20	17.12	19.4	0.88	0.58	0.36	-0.52
	Upper Orashi River	99.40	67.80	31.60	31.8	0.82	0.77	0.54	-0.28
	Ikebiri Creek	67.23	67.13	0.10	0.1	0.87	0.48	0.37	-0.5
	Egbedi Creek	64.40	61.70	2.71	4.2	0.46	0.31	0.19	-0.27
	Lower Orashi River	40.10	26.30	13.83	34.4	0.52	0.44	0.39	-0.13
Mangrove	Uwet Odot	243.10	127.40	115.7	47.6	0.29	0.18	0.11	-0.18
	Uremure Yokri	328.80	291.04	37.80	11.5	0.88	0.82	0.79	-0.09
	Olague	234.20	159.71	74.53	31.8	0.59	0.53	0.45	-0.14

Table 5.5 was used to select case studies of deforestation and degradation in forest reserves and national parks, located in different forest types, which is to be discussed in the following section. Selection is based on the type of forest, the amount of forest left, the nature of degradation in each forest reserve (e.g deforestation versus degradation), and sometimes the literature explaining the nature of the problem in the area in question, in order to help elucidate the causes of such degradation. In lowland rainforest, four major case studies are presented: Okomu, Gilli-Gilli, Umon Ndealichi and Sambrero; while three case studies are presented from freshwater swamp forest: Taylor Creek, Osomari and Egbedi Creek. Only three forest reserves (Uwet Odot, Uremure Yokri and Olague) are located within mangrove, and these forest reserves have lost about 47.6%, 11.5% and 31.8% respectively (Table 5.5). These three forest reserves (Uwet Odot, Uremure Yokri and Olague) are presented as case studies of mangrove deforestation, though they have low deforestation and degradation rates.

Though, there is little available information about the origins, nature and deforestation in these reserves, it is obvious from Table 5.5 that their rate of degradation varies from forest reserves located in the lowland rainforest, freshwater swamp and mangrove. This was higher in lowland rainforest compared to freshwater swamp and mangrove forests.

For lowland rainforest, Okomu forest reserve tops the table in terms of area of forest left and level of NDVI reduction, while Taylor Creek and Uremure Yokri top the table for freshwater swamp forest and mangrove (Table 5.5). The situation within these forest reserves are analysed and compared in the subsequent sections.

Increase in deforestation of reserves has many implications on biodiversity in the Niger Delta of Nigeria. The animals in many of these degraded forests are threatened, and some might already be extinct (Figure 5.14). Blench (2007) has noted that numerous endemic mammals are located in lowland forest region of the Delta, many of which are endangered, for example, the White-throated guenon; Red colobus monkey and Scatter's monkey (Figure 5.14). Other studies have also shown that many of these mammals are endangered or threatened (Baker and Olubode 2007; Fagade 2010; Akinsorotan *et. al* 2011), probably due to change in landuse and forest degradation in the region as seen in our results (Figure 5.14). For example, Niger Delta pygmy hippopotamus is found in the freshwater swamp forest of the Niger Delta (Figure 5.14), and the results from the present study have shown that it is located in highly degraded areas (Figure 5.14), and this might be the reason for its danger of extinction as recorded by earlier studies (e.g. Blench 2007). To have a greater understanding of changes in the Delta, this study further examines these issues using the case studies, the results of which are presented below.

5.1.3. *Results of Case Studies*

This section presents the results of the specific case studies of landuse change and forest degradation in the different forest types identified above. The case studies enhance spatiotemporal information and quantification of environmental change in the Delta by employing a more detailed temporal analysis, as all cloud free images in the Landsat zone that were found have been processed, in order to study environmental change in more details.

5.1.3.1. Deforestation in Lowland Rainforest Reserve: The Case of Okomu and Gilli-Gilli Forest Reserves

Okomu and Gilli-Gilli forest reserves are located in Ovia South-West Local Government Area of Edo State of Nigeria (Figure 5.15). Both forest reserves are the home of threatened wildlife including White-throated monkey, Forest elephant, and African buffalo (USAID/Nigeria 2008). Akinsorotan *et al* (2011) also noted that Okomu forest reserve is a home to numerous other important species that are locally threatened, including three species of antelope: Maxwells duiker (*Cephalophus maxwelli*), Yellow-backed duiker (*Cephalophus silvicultor*), and Red-flanked duiker (*Cephalophus rufilatus*); four primate species: Red-capped mangabey (*Cercocebus torquatus*), Mona monkey (*Cercopithecus mona*), White-throated monkey (*C. erythrogaster pocoki*), and Putty-nosed monkey (*C. nictitans ludio*); and a species of mangoose (*Herpestes sp).*

Figures 5.16 shows the spatial and temporal rate of deforestation within Okomu forest reserve, while Figure 5.17 shows the change in landuse within the forest reserve over the study period. The trends in landuse change in the reserve are presented in Figure 5.18, the trends in forest area and NDVI values are shown in Figure 5.19, while Figure 5.20 is used to compare the rate of deforestation between Okomu and Gilli-Gilli forest reserves.

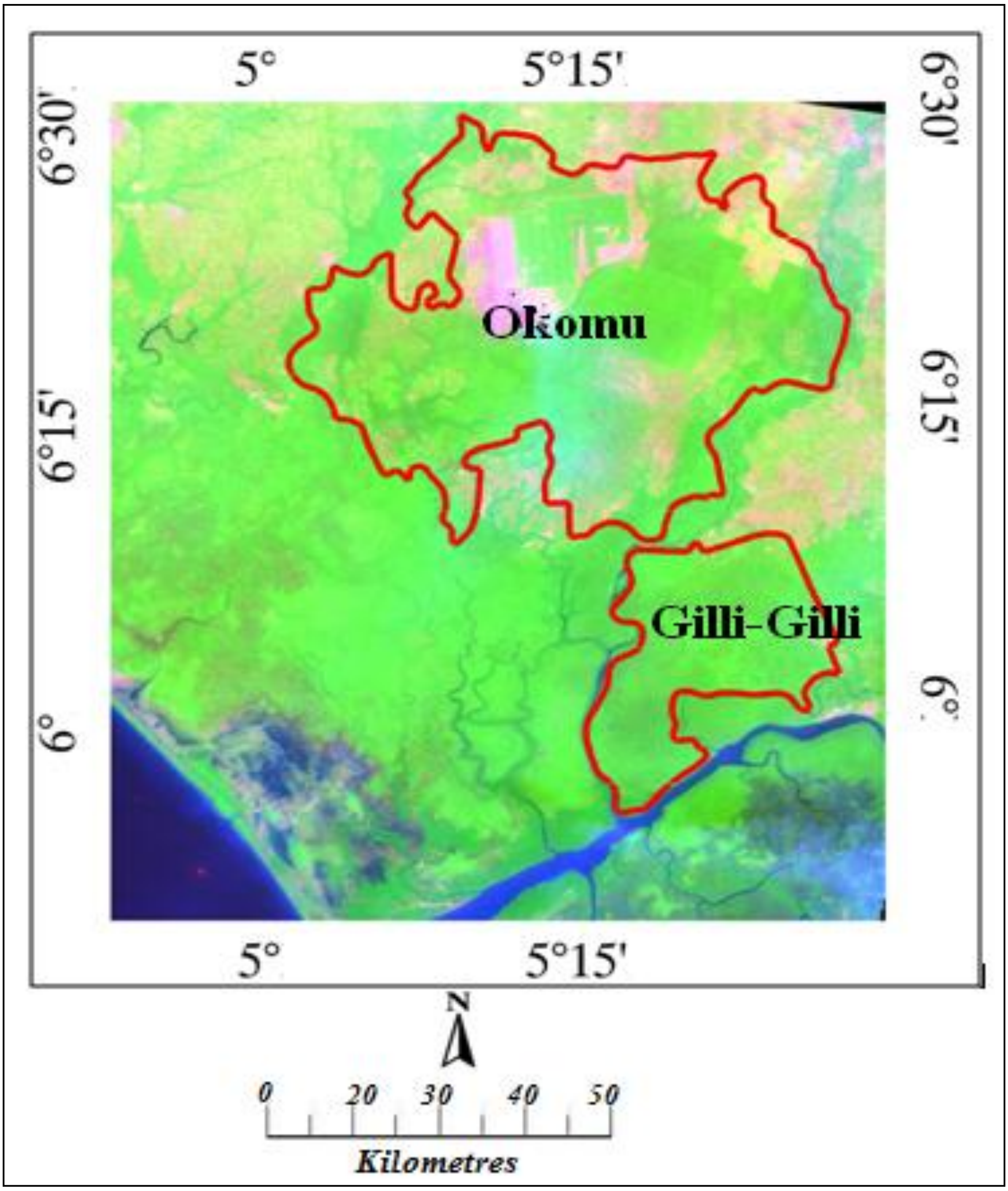


Figure 5.15. Map of the Western part of the Niger Delta of Nigeria, showing location of Okomu and Gilli-Gilli forest reserves

Between 1984 and 2011, it is clear (Table 5.6) that 46.1% of the forest cover in Okomu has been lost. The forest area reduces from 1118km^2 in 1984 to 603 km^2 in 2011. These values reveal significant deforestation due to farmland expansion of over 100%. Two major locations of farmland expansion can be observed within the reserve, one in the north and one in the south (Figures 5.17). Thus, farmland expansion accounts for the major cause of deforestation within the forest reserve. In 1984, the area covered by farmland was about 5.6%out of the total area of Okomu forest reserve, but it had expanded to 43.7% by 2011 (Table 5.7 and Figures 5.16 and 5.19).

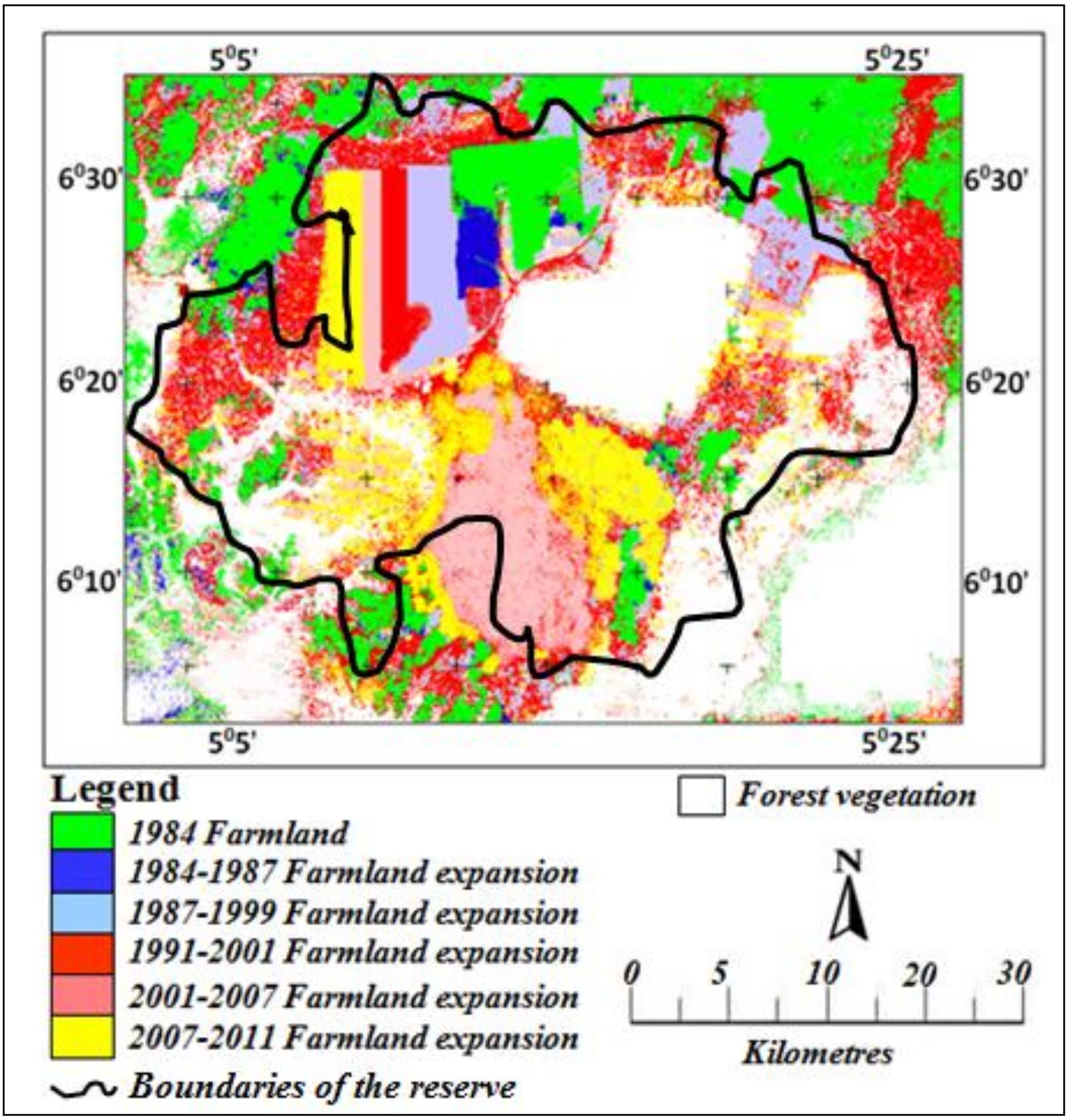


Figure 5.16. Farmland expansion in Okomu forest reserve

Table 5.6. Rate of change in landuse within Okomu forest reserve between 1999 and 2011 (in km^2).

Landuse Class	1984	1987	1999	2001	2007	2011	1984-2011 %Change
Urban	34.81	35.46	35.55	38.25	38.42	38.84	11.6
Forest	1117.78	1019.32	937	799.56	689.5	602.73	-46.12
Farmland	196.48	294.29	376.52	511.26	621.15	707.5	167.11

Table 5.7. Percentage of area cover by farmland and forest within Okomu forest reserve between 1999 and 2011

Year	Areas Covered by Farmland (%)	Areas Covered by Forest (%)
1984	5.61	82.89
1987	6.32	76.11
1999	21.10	73.91
2001	25.41	63.12
2007	32.42	56.22
2011	43.70	51.73

The annual rate of deforestation in the reserve varies being 0.9% between 1980 and 1987, 0.8% from 1987 to 1999 and 1.3% from 2001 to 2007 (Table 5.8). However, the rate of farmland expansion is increasing, apart from a small reduction between 2001- 2007. This is interesting because on the whole, throughout the Delta, the annual rate of farmland expansion is declining. This case study implies that though there are ongoing reductions in farmland expansion in the whole of the Delta, there are some specific locations where farmland appears to increase, as in this case of a forest reserve. Thus, the results imply that the major driver of deforestation in Okomu is the expansion of farmland.

Table 5.8. Annual rate of change in major landuse in Okomu (%).

Rate of change	**1984-1987 (Annual % Change)**	**1987-1999 (Annual % Change)**	**1999-2001 (Annual % Change)**	**2001-2007 (Annual% Change)**	**2007-2011 (Annual % Change)**
Deforestation	0.90	0.82	0.62	1.31	0.93
Farmland	3.12	4.51	4.60	4.22	4.90

The NDVI results similarly, show a reduction in the mean values of NDVI over the study periods (Figure 5.19). These values imply that the remaining forest vegetation is increasingly being degraded in this reserve, perhaps due to selective logging, fuel wood collection and maybe even subsistence farming under the forest canopy. Thus, it is obvious from both classification and NDVI results that Okomu forest reserve has been largely consumed by the wave of expansion of agriculture. This occurred largely by the introduction of oil palm plantations and the Taungya system in the reserve (See Chapter 2). Several studies have shown that Taungya system has failed (Oates 1995; Menzies 1988; Hellermann 2007), and its introduction has played a significant role in the high rate of deforestation.

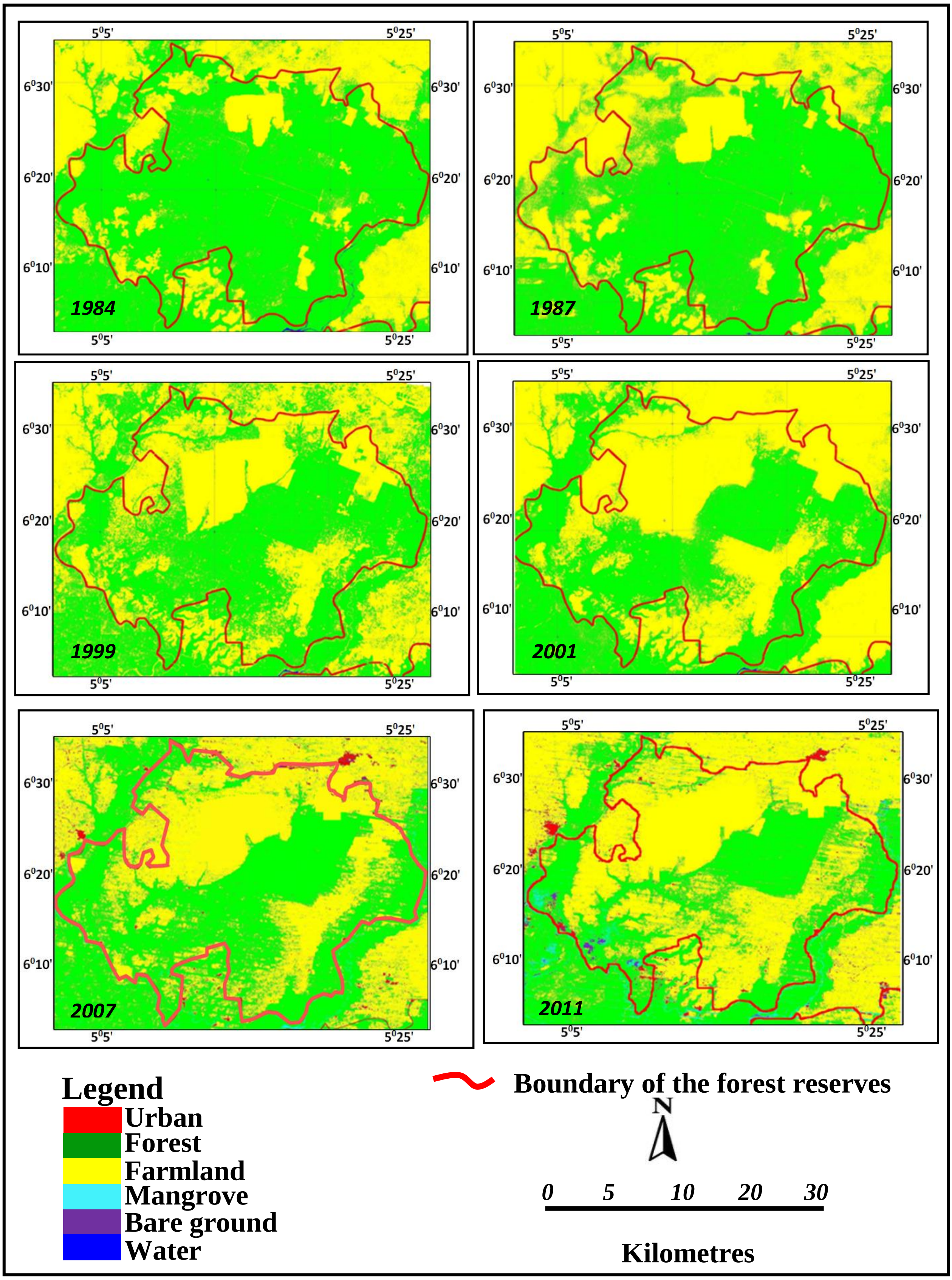


Figure 5.17. Landuse change in Okomu forest reserve

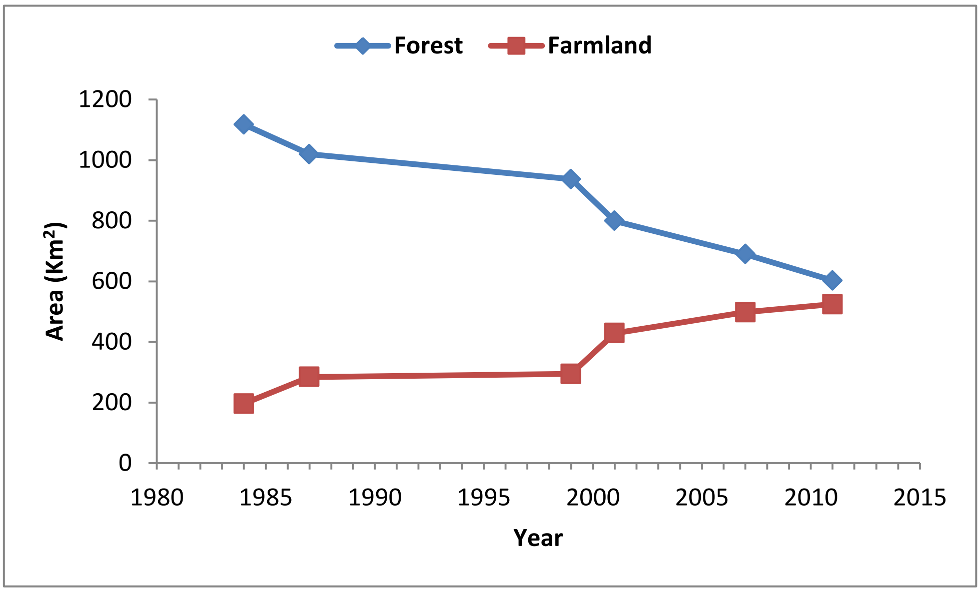


Figure 5.18. Changes in forest and farmland in Okomu forest reserve

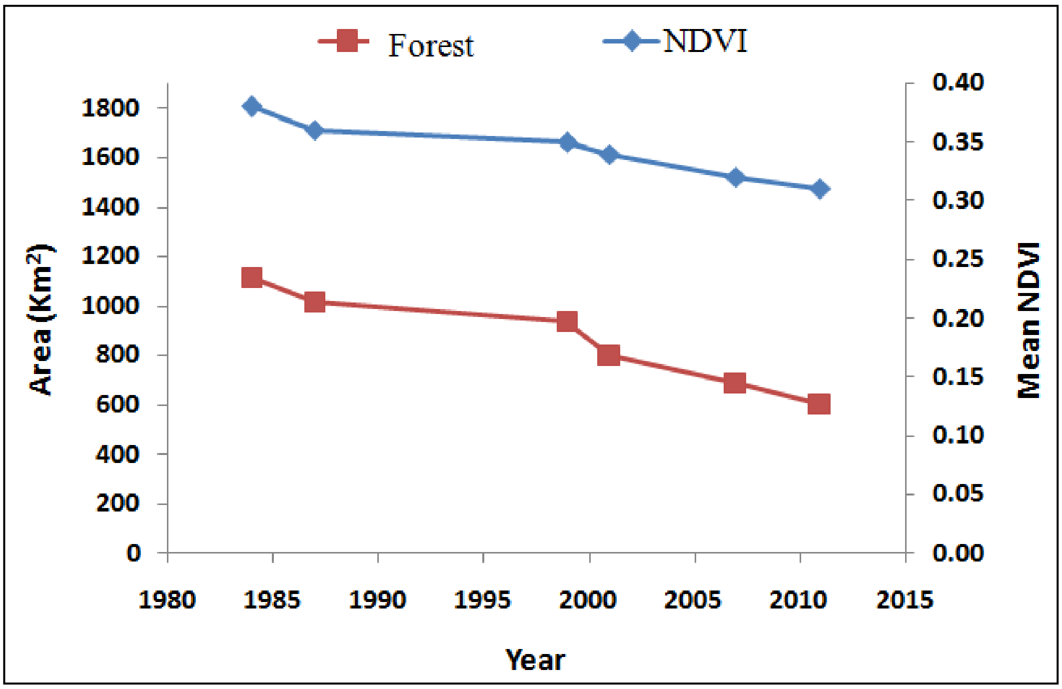


Figure 5.19. Changes in Okomu forest reserve from 1984 to 2011

When the results from Okomu forest reserve are compared with that of Gilli-Gilli forest reserve (Figures 5.18 and 5.20), a large difference is clear. Forest disturbance within Gilli-Gilli forest reserve is much less than Okomu forest reserve, consisting of a little forest degradation on the Northern side of Gilli-Gilli (Figures 5.18 and 5.20). Variations in the rate of deforestation between the two forest reserves can be attributed to a wave of deforestation gradually spreading southeast over the time. Okomu has been largely consumed by this wave of expansion and Gilli-Gilli appears to be experiencing the first effects along its Northern margin, thus making access as an important factor in limiting deforestation, to be suggested.

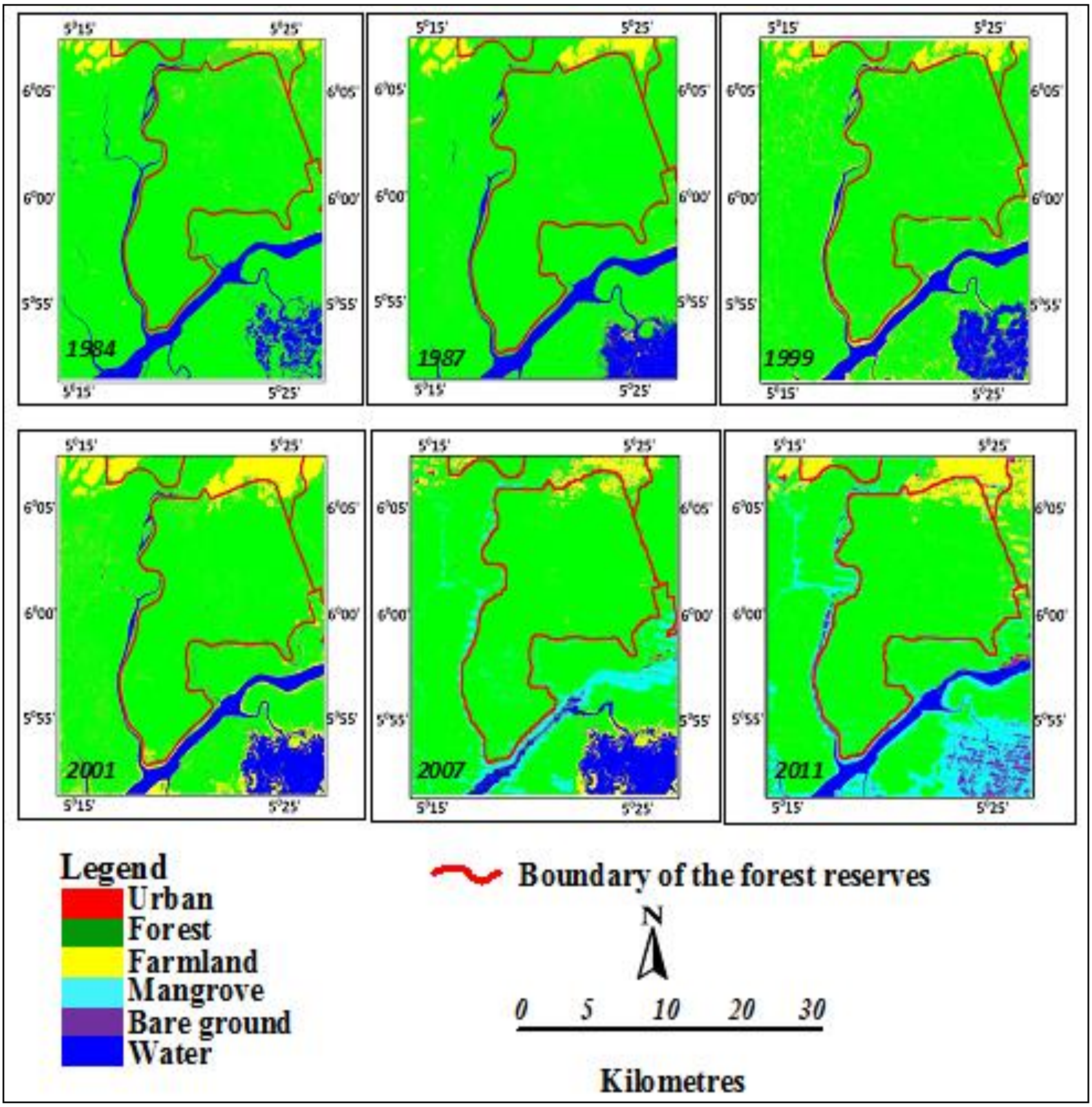


Figure 5.20. Changes in forest and farmland around Gilli-Gilli forest reserve

5.1.3.2. Deforestation in Freshwater Swamp Forest Reserve: A Case Studies of Osomari, Bayelsa National Park, Sambrero, and Egbedi Forest Reserves

Osomari, Taylor/Bayelsa National Park, Sambrero, and Egbedi forest reserves are located in the freshwater swamp forest, at the centre part of the Niger Delta (Figure 5.21). The historical records of the status of wildlife in these reserves are limited, but studies have shown a past record of Niger Delta pygmy hippopotamus in Egbedi Forest Reserve (UNEP-WCMC 2007; Blench 2007), and USAID/Nigeria (2008) also recorded that endangered endemic red colobus monkey is located in Taylor/Bayelsa National Park. Figure 5.22 shows spatial-temporal change of landuse in the forest reserves between 1987 and 2011. It is evident that much deforestation occurs within Sambrero and Osomari, which both have lost almost 50% of their vegetation. For instance in Sambrero, the area covered by forest was about 117km^2 in 1987, but was reduced to 88km^2 in 2011 (Table 5.9). Likewise from the same Table 5.9, the area of Osomari declined from 81km^2 in 1987, to 49km^2 in 2011. In contrast, few changes occur within Taylor/Bayelsa National Park and Egbedi forest reserve (Figures 5.22 and 5.23). Between 1987 and 2011, only 1.9 % and 6.3% of forest were lost within both Taylor/Bayelsa National Park and Egbedi forest reserves respectively (Table 5.9 and Figure 5.23).

The NDVI results also revealed a small reduction in the rate of forest degradation in the reserves. In general, there appears to be much degradation within these forest reserves during 1980s, but the rate of forest degradation has been less since then (Figure 5.24). Sambrero and Osomari appear to have been much more degraded, compared with other forest reserves in this category (Figure 5.24). They appear to be suffering from both severe deforestation and also, the remaining forest is suffering degradation.

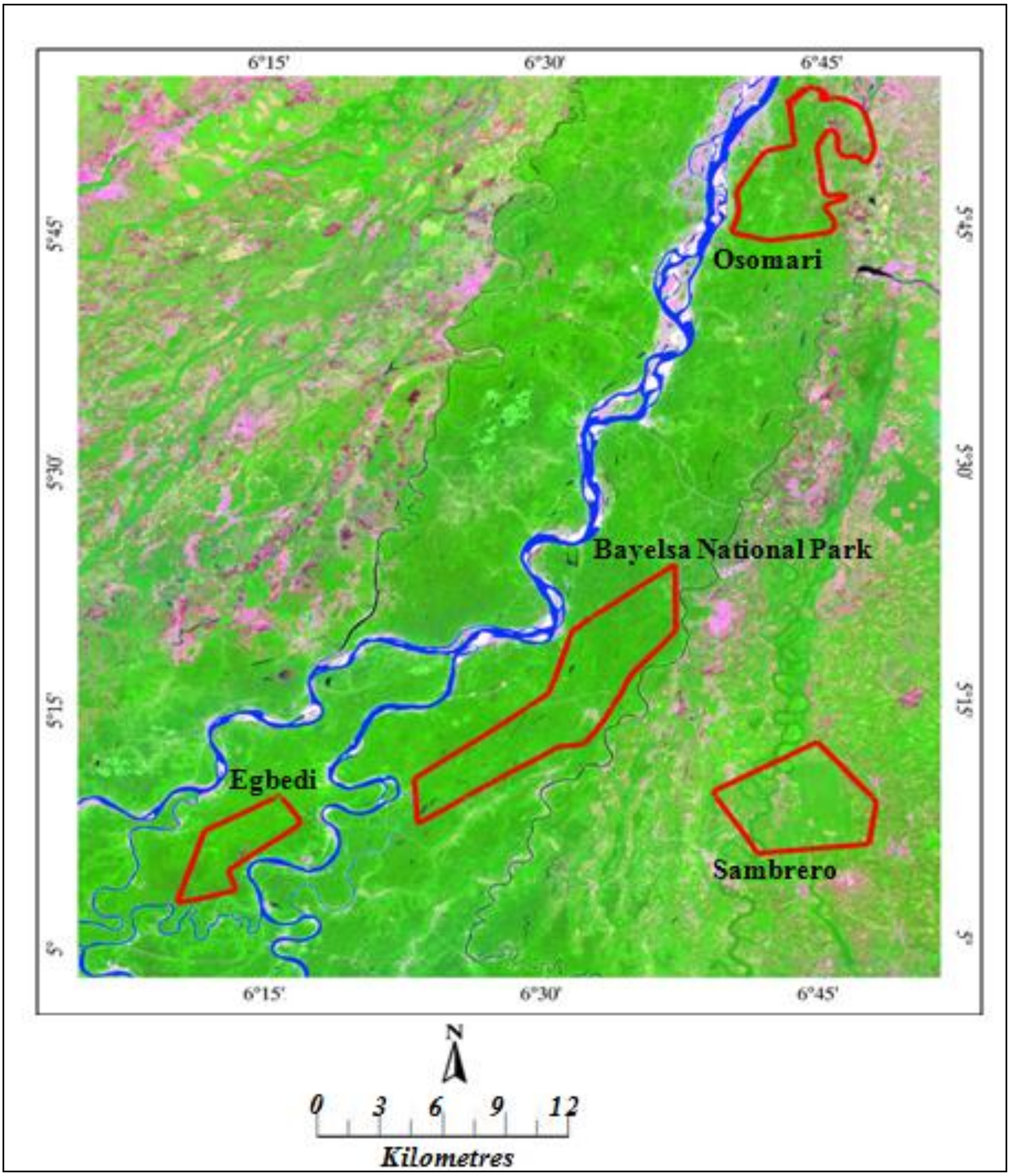


Figure 5.21. Map of the centre part of the Niger Delta, showing the location of Osomari, Bayelsa National Park, Sambrero, and Egbedi forest reserves

Table 5.9. The rate of deforestation within Osomari, Bayelsa National Park, Sambrero, and Egbedi forest reserves between 1987 and 2011.

Forest reserve	**1987 (km^2)**	**1990 (km^2)**	**2002 (km^2)**	**2008 (km^2)**	**2011 (km^2)**	**1987-2011 % Change**
Osomari	117	104	101	90	88	-24.82
Taylor and Bayelsa National Park	214	213	212	211	210	-1.91
Sambrero	81	69	67	52	49	-39.52
Egbedi	63	62	62	61	59	-6.30

The inter-annual rate of deforestation in all these reserves is low, but there are small variations between the four forest reserves. The rate increased slightly in Osomari, but decreased in Sambrero, while Taylor and Bayelsa National Park and Egbedi stayed the same (Table 5.10). In general, inter-annual rate of deforestation of these forest reserves are all much lower than Okomu.

Table 5.10. Annual rate of deforestation in major landuse in Osomari, Bayelsa National Park, Sambrero and Egbedi forest reserves (%).

Rate of Deforestation	**1987-1999 (Annual % Change)**	**1999-2002 (Annual % Change)**	**2002-2008 (Annual % Change)**	**2008-2011 (Annual % Change)**
Osomari	0.11	0.20	0.30	0.21
Taylor and Bayelsa National Park	0.01	0.01	0.01	0.01
Sambrero	0.31	0.20	0.12	0.11
Egbedi	0.02	0.01	0.01	0.01

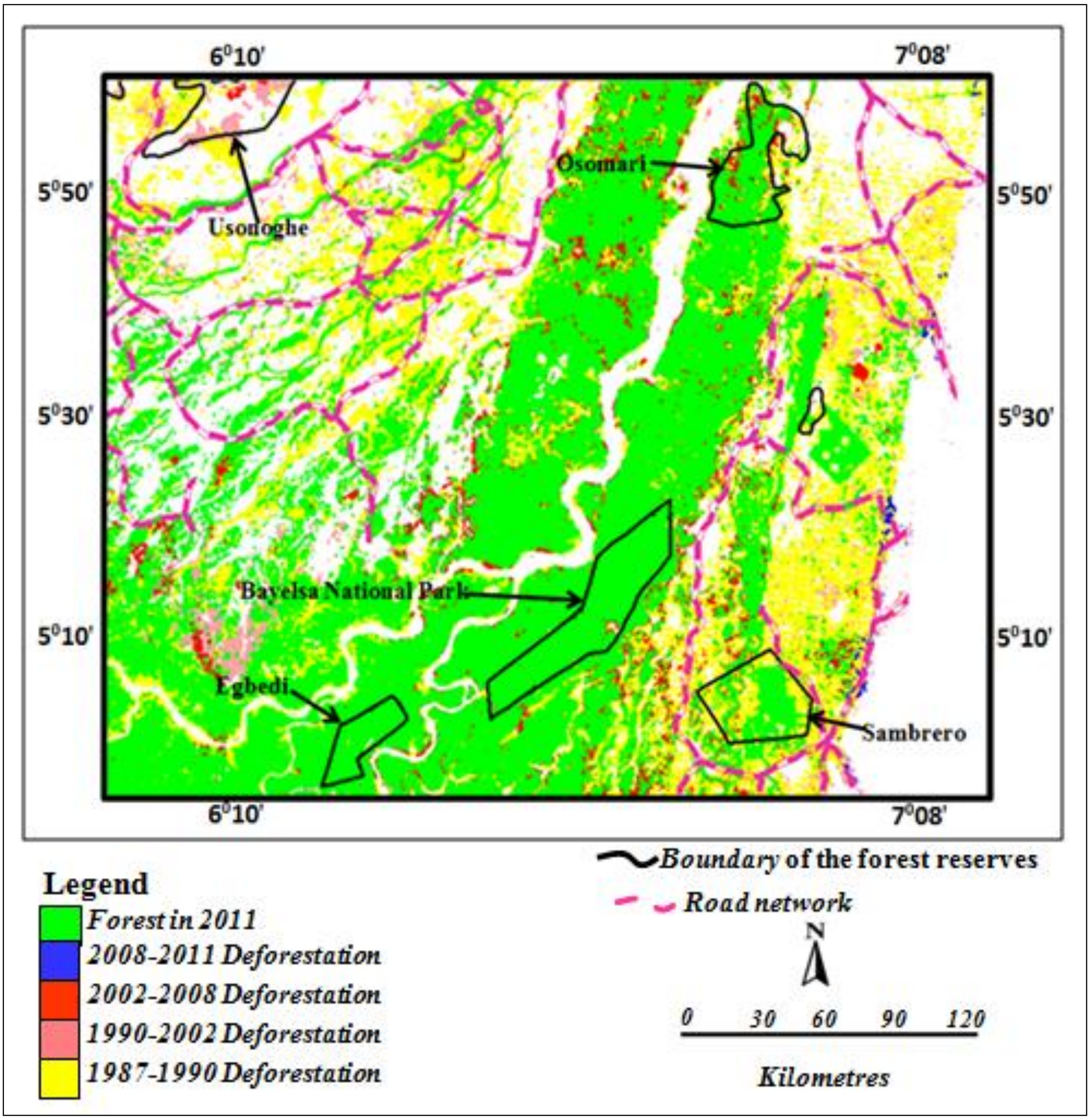


Figure 5.22. Deforestation in Osomari, Bayelsa National Park, Sambrero, and Egbedi forest reserves

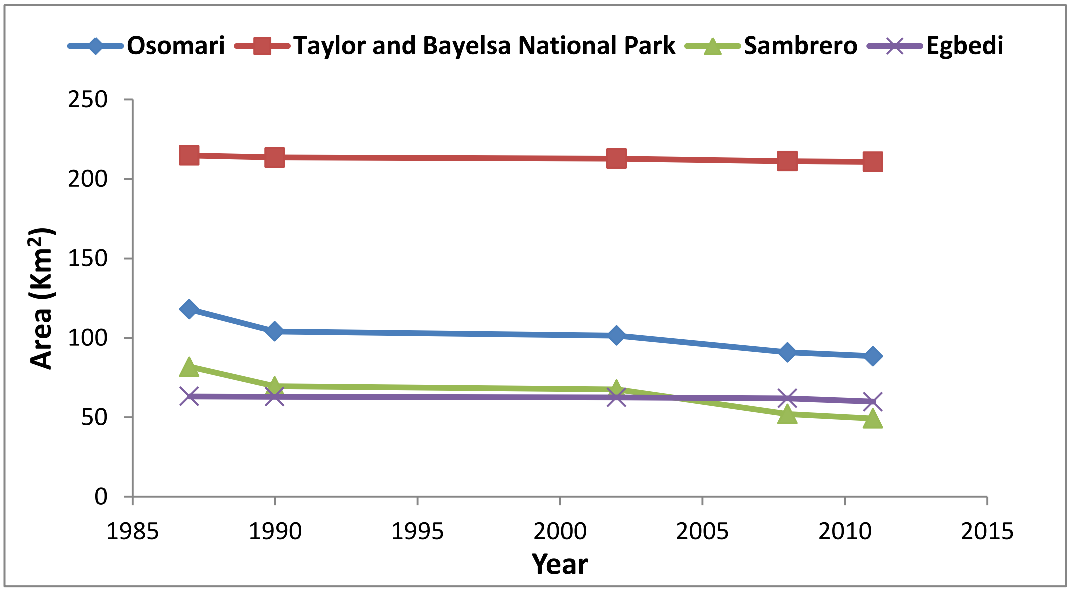


Figure 5.23. Deforestation in Osomari, Bayelsa National Park, Sambrero, and Egbedi forest reserves between 1987 and 2011

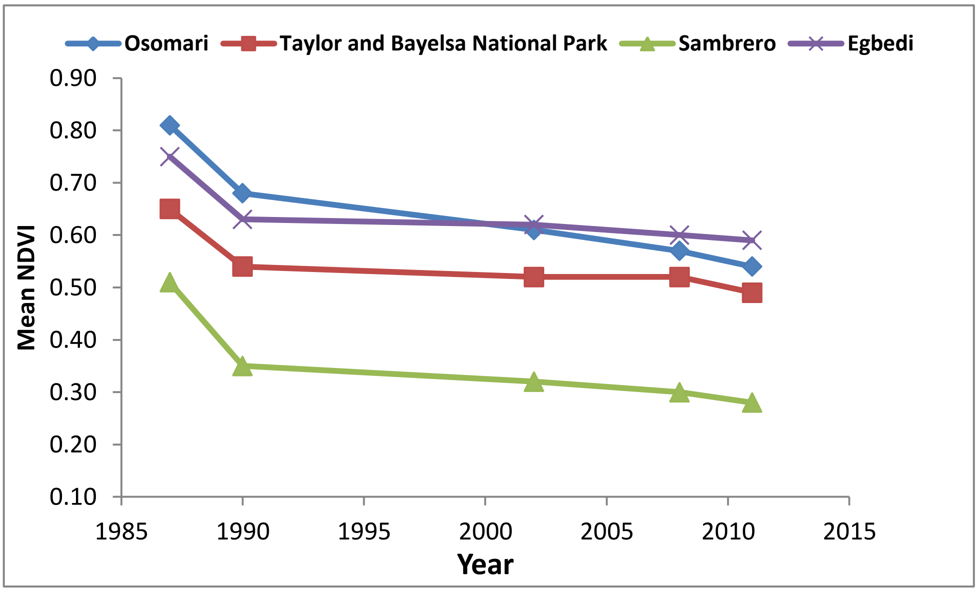


Figure 5.24. Changes in mean NDVI for Osomari, Bayelsa National Park, Sambrero and Egbedi forest reserves between 1987 and 2011.

The patterns of deforestation observed above could be due to three main factors: Firstly, Sambrero and Osomari appear to be located at the boundary of two forest types: freshwater swamp and lowland rainforest. As higher deforestation is noted within lowland rainforest, a wave of which spread and intensify along the boundary of the lowland forest, where both Sambrero and Osomari are located, and this has presumably contributed to deforestation in the reserve (Figure 5.22). It is evident from Figure 5.22 also that both Taylor/Bayelsa National Park and Egbedi forest reserve are located within the centre of freshwater swamp forest and this lack of access might have helped to protect them. Secondly, several roads have been constructed very close to both Sambrero and Osomari forest reserves (Figure 5.22). This permits accessibility of local people to the reserves; thus encouraging rapid deforestation by commercial selective logging; as well as degradation through access by local people to collect firewood; and selective logging of the forests.

There are few literatures about the nature and rate of degradation in these forest reserves under discussion. Although, Luiselli and Akani (2003) reported that the main factor, which might be responsible for high rate of degradation within the Osomari, Taylor/Bayelsa National Park, Sambrero, and Egbedi forest reserves during 1980s was the introduction of oil exploration.

5.1.3.3. Deforestation in Mangrove/Rainforest Forest Reserves: A Case of Umon Ndealichi and Uwet Odot Forest Reserves

Figure 5.25 shows the location of Umon Ndealichi and Uwet Odot forest reserves. Both reserves are located between Calabar and harbour a high diversity of primates such as the Cross River gorilla, Drill monkey, Vellerosus chimpanzee, Preuss' guenon, Red colobus monkey, Sclater’s guenon, Angwantibo, Grey-necked picathartes and Xavier’s greenbul (UNEP-WCMC 2007; Blench 2007; Morakinyo and Tooze 2007; USAID/Nigeria 2008).

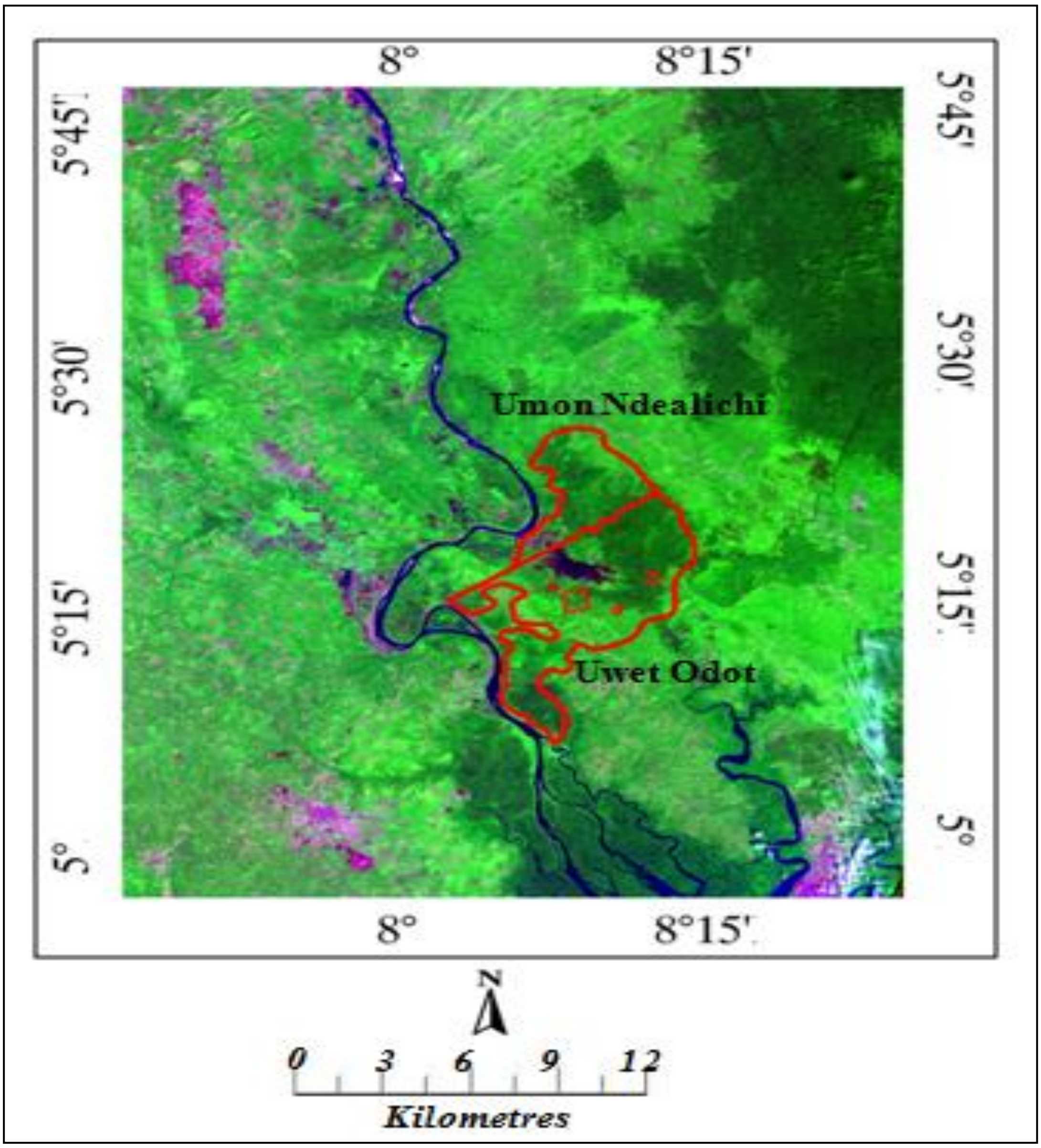


Figure 5.25. Map of the Eastern part of the Niger Delta of Nigeria, showing location of Umon Ndealichi and Uwet Odot Forest Reserves.

Less deforestation is evident within Umon Ndealichi (11.6 %), than at Uwet Odot (33.3%) (Table 5.11). The inter-annual rate of deforestation is similar throughout the period of study in Umon Ndealichi (0.01%), but for Uwet Odot, it is lower but varies, and there does not appear to be a trend in the variation (Table 5.12). There appears to be a lower rate of deforestation in freshwater and mangrove compared to Okomu. The mean NDVI trend also depicts gradual forest degradation within Umon Ndealichi forest reserve throughout the periods. However, trend in mean NDVI shows a rapid degradation within Uwet Odot (Figure 5.28), that probably affects the wildlife resources within the reserve.

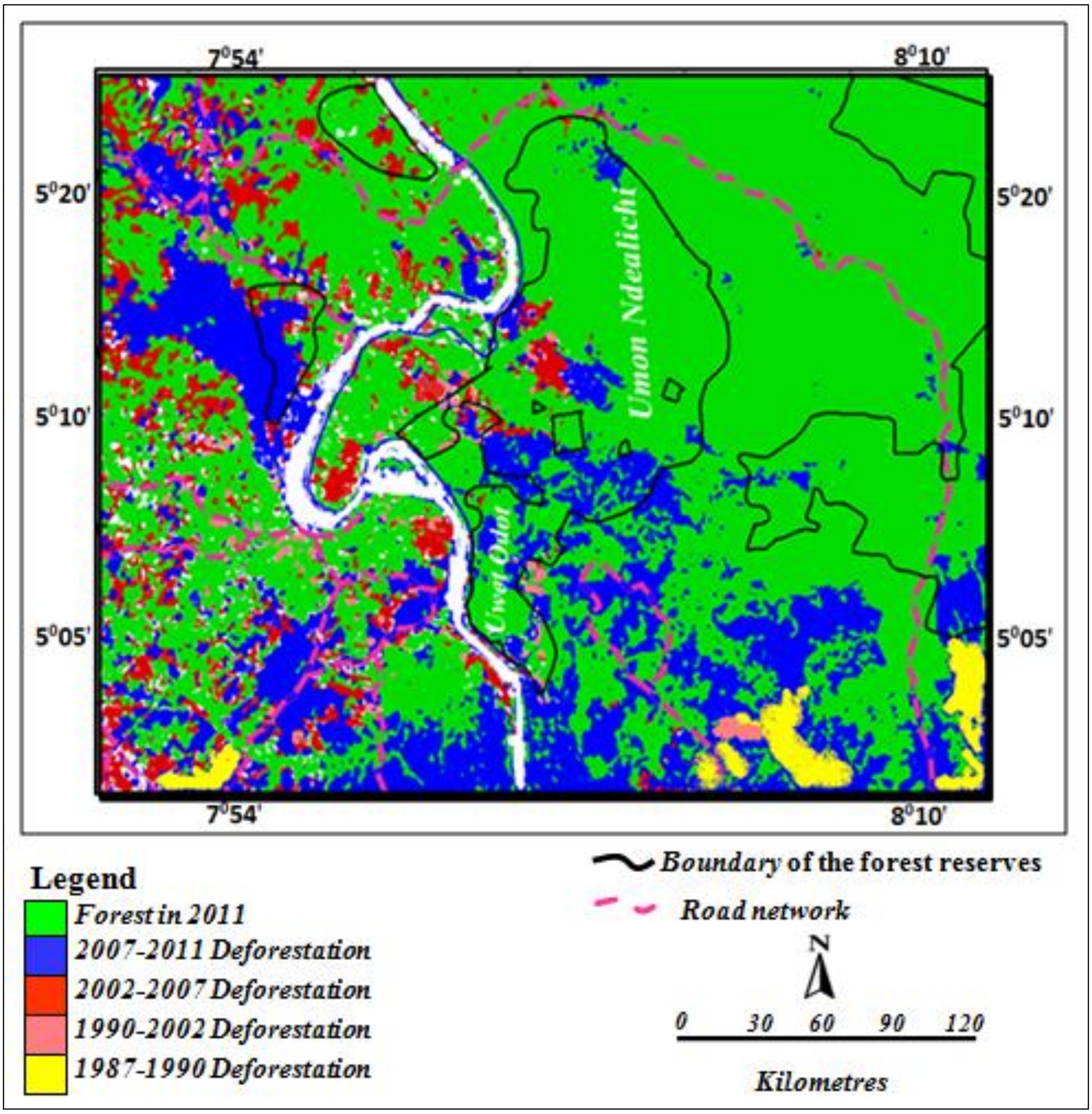


Figure 5.26. Deforestation in Umon Ndealichi and Uwet Odot Forest Reserves

Table 5.11. The rate of deforestation in Umon Ndealichi and Uwet Odot forest reserves between 1984 and 2011

Forest reserve	1984 km^2	1986 km^2	2000 km^2	2003 km^2	2007 km^2	2011 km^2	1984-2011 (% Change)
Uwet Odot	201	200	184	183	168	134	-33.31
Umon Ndealichi	86	85	79	78	77	76	-11.60

Table 5.12. Annual rate of deforestation in major landuse in Umon Ndealichi and Uwet Odot forest reserves (%)

Rate of Deforestation	1984-1986 (Annual % Change)	1986-2000 (Annual % Change)	2000-2003 (Annual % Change)	2003-2007 (Annual % Change)	2007-2011 (Annual % Change)
Uwet Odot	0.01	0.04	0.01	0.02	0.03
Umon Ndealichi	0.01	0.01	0.01	0.01	0.01

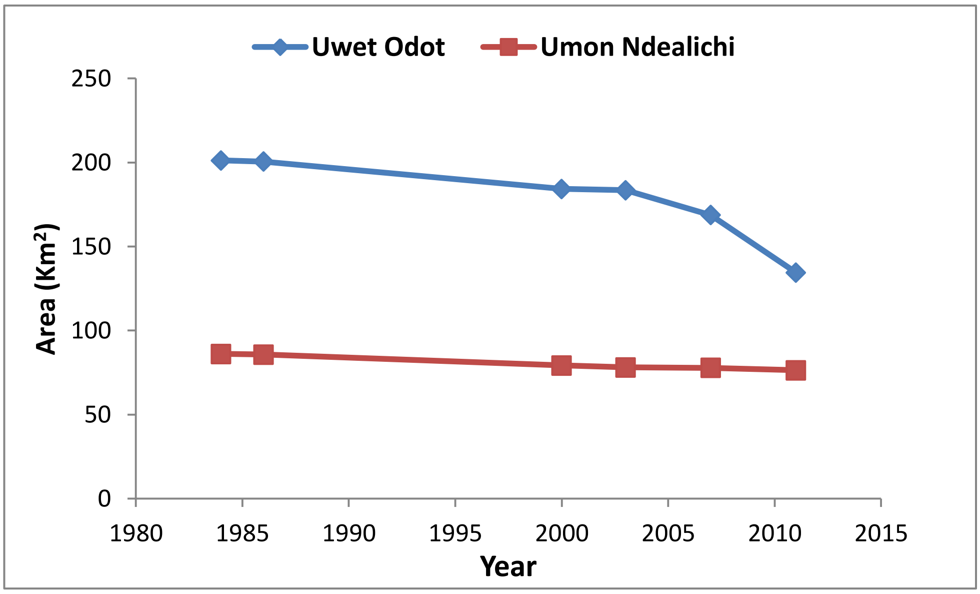


Figure 5.27. Changes in Umon Ndealichi and Uwet Odot forest reserves between 1984 and 2011

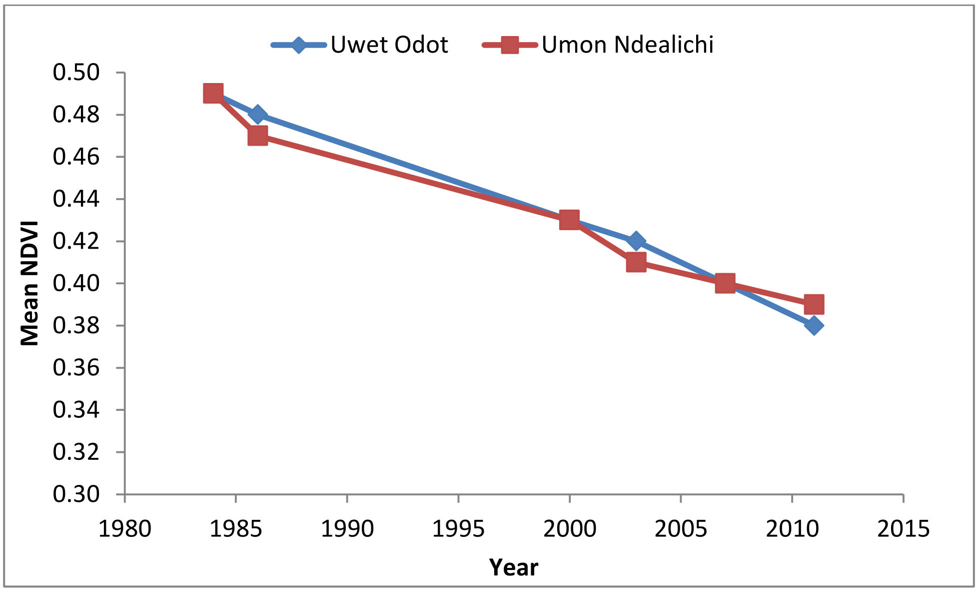


Figure 5.28. Changes in mean NDVI for Umon Ndealichi and Uwet Odot forest reserves between 1984 and 2011

These deforestation and degradation are probably due to the construction of several roads in close proximity to Uwet Odot, thus increasing the accessibility to the reserve (Figure 5.26). Moreover, Uwet Odot is located closer to one of the most highly populated cities in the Delta, Calabar. Demand for forest resources by these cities, due to increasingly growing population, might be responsible for rapid forest degradation noted in Uwet Odot and Umon Ndealichi forest reserves (Ite 2001; 2005; Babalola 2009; Ezebilo and Mattsson 2010b). Studies by Ite (1995 and 2005) have further reported that selective logging and local agricultural practices could be linked to wider rate of forest loss in the protected areas along Cross Rivers. Ezebilo and Mattsson (2010b) also noted that majority of people in this community, could not do without cutting trees, because it is their main source of fuel for cooking. Though, there is little specific information on the impacts of forest loss on these reserves, it is clear that in the past three decades, intense human activities such as large-scale illegal logging and clearing of forest for plantation agriculture and farmlands; and uncontrolled hunting have led to a severe decline of wildlife throughout the Delta (Morakinyo and Tooze 2007; USAID/Nigeria 2008). Moreover, Morakinyo and Tooze (2007) further reported that the major problem is that many rural communities surrounding these forest reserves are traditional hunters and farmers, who see the forest reserves as hunting grounds (Babalola 2009; Ajake and Anyandike 2012). The situation at present is that wildlife are seriously threatened (Ezebilo 2010). So, the results from present study, like other previous studies, show the need for urgent forest conservation, not only within forest reserves in the Niger Delta, but all over the country.

5.1.3.4. Urban Expansion: A Case of Okitipupa/Irele

The remote sensing methods developed in this thesis are effective at mapping urban expansion, which is illustrated well by the growth of Okitipupa/Irele. Okitipupa/Irele is located in Ondo state, a new member state of the Niger Delta (Figure 5.29). Figures 5.30 and 5.31 present the expansion of Okitipupa/Irele between 1984 and 2011. The area covered by Okitipupa/Irele has increased by almost 60% (Figure 5.31), between 1984 (18 km^2) and 2011 (46km^2). A huge expansion is noted from 1984 to1987 (Figure 5.30), but the expansion of the urban area has gradually slowed down during 1999 to 2011 (Figure 5.31). The major expansion is towards the south-west over the periods of study (Figure 5.31).

Two factors could be responsible for this: Socio-economic development and Increase in population. The first and the most important factor appears to be in line with the development of road infrastructure, as much of the recent development appears to have occurred along these route ways. The increase in population is another factor. The population of Okitipupa/Irele was less than 42,500 as at 1980s, according to the National population census, but the population increased to over 210,250 in 2001 (NDDC 2001), although, there are fewstudies about the rate of expansion in Okitipupa/Irele. The most important factor

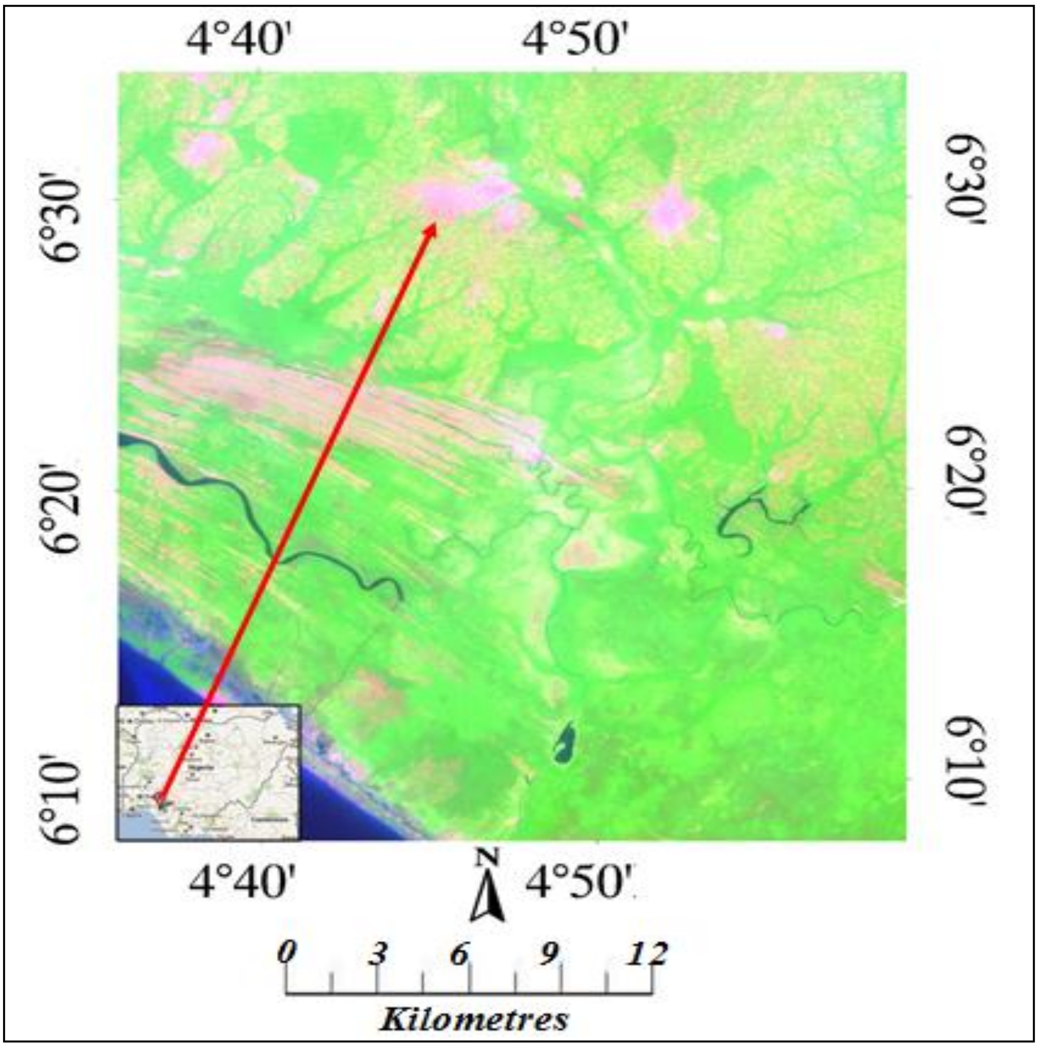


Figure 5.29. Map of the Western part of the Niger Delta of Nigeria, showing the location of Okitipupa/Irele

responsible for this population increase and associated urban expansion in Okitipupa/Irele is socio-economic development, since Okitipupa became the central town of Local Government (Faleyimu 2014), with a major modern market built in 1980. These socio-economic developments have attracted population and many industries such as Okitipupa Oil Palm Plc and Oluwa Glass Factory, whichappears to have contributed to increase in Okitipupa population and the associated changes already outlined above.

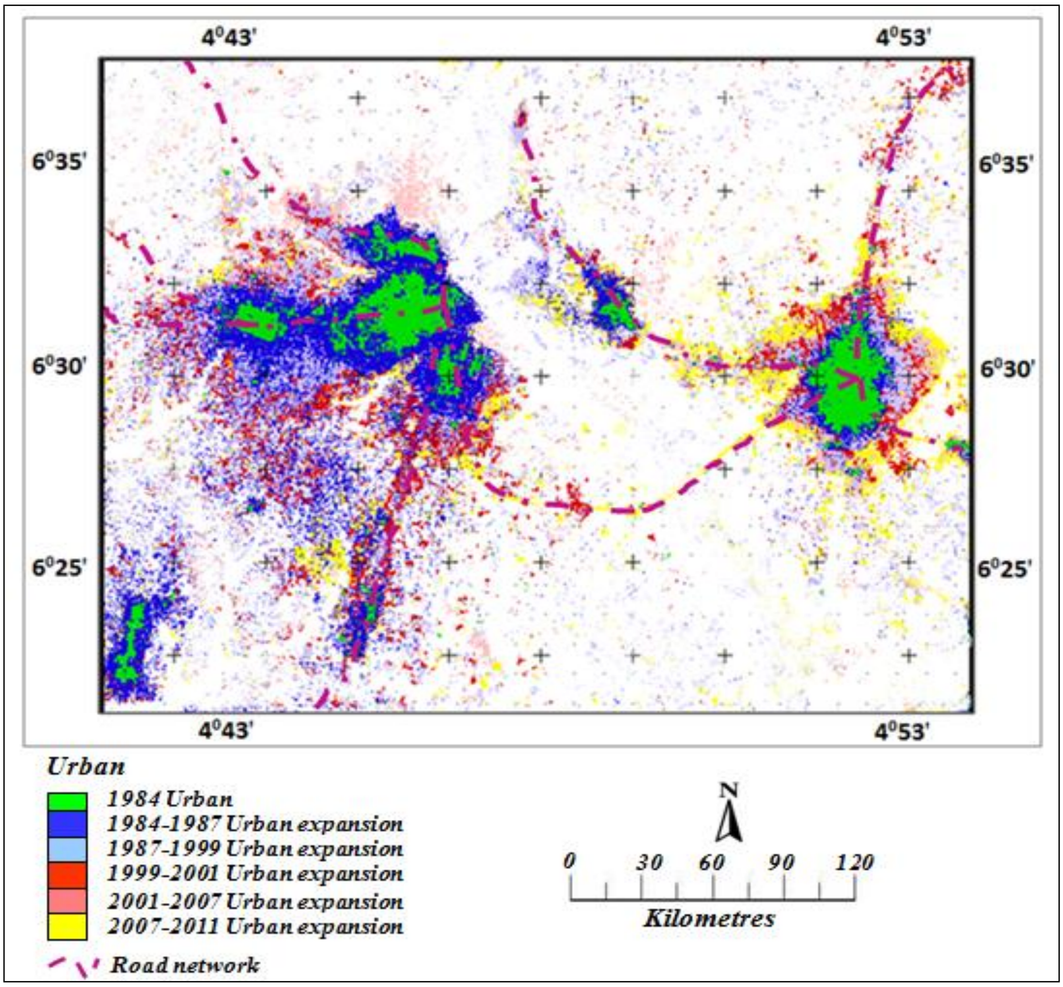


Figure 5.30. Spatiotemporal changes in urban areas around Okitipupa and Irele communities

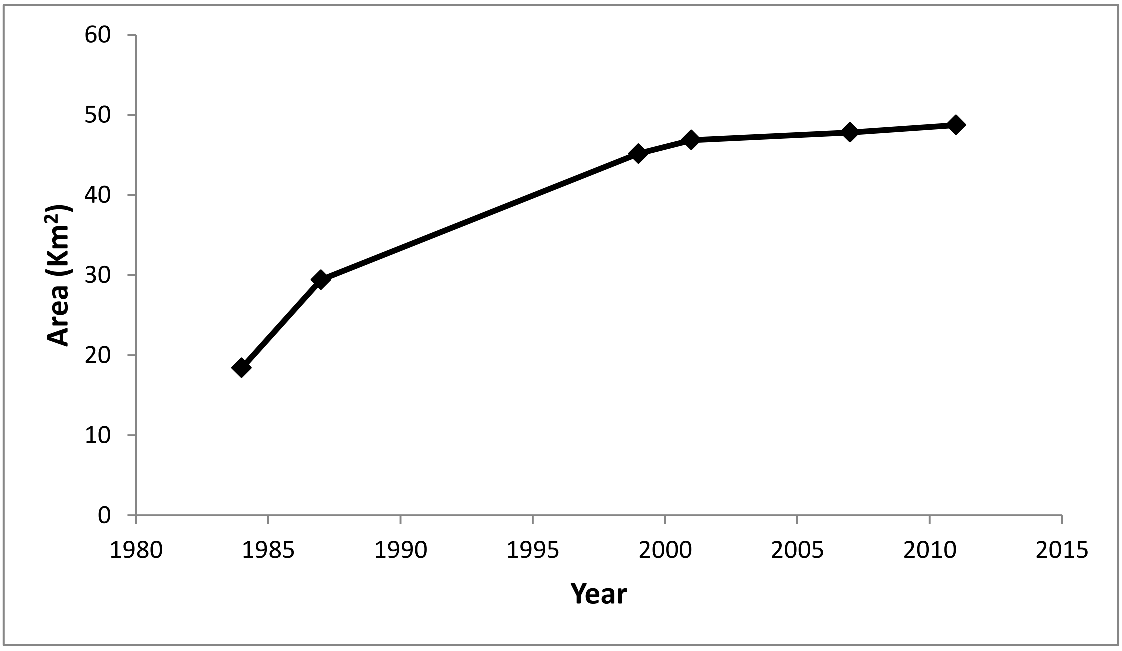


Figure 5.31. Temporal changes in Okitipupa and Irele between 1984 and 2011

5.1.3.5. Expansion in Warri

Warri is one of the major industrial towns in Delta State of the Niger Delta (Iwegbue *et. al.* 2012) as seen in Figure 5.32, which has expanded rapidly over the period of study. The city was just 115km^2 in 1987 and expanded to 224 km^2 in 2011 (Figure 5.34), thus from 1990 to 2011, the city has expanded by approximately 50% (Figure 5.33). Initially, the city expanded mainly towards the south during 1980s and 1990s, but the expansion is predominantly towards the north and east from then on (Figure 5.33). Two factors might be responsible for this pattern. The city appears to expand along road networks in the north-east, while it is impossible to expand towards west and southern parts, due to the presence of swamps, rivers and creeks (Figure 5.33). The north-east is the driest part of the city with well drained soils. Thus, the city expanded to south during 1980s and 1990s to cover the good ground, but between 1990 and 2011, urban expansion was largely towards the northern and east, possibly because the there are no well-drained soil left along south and west for construction.

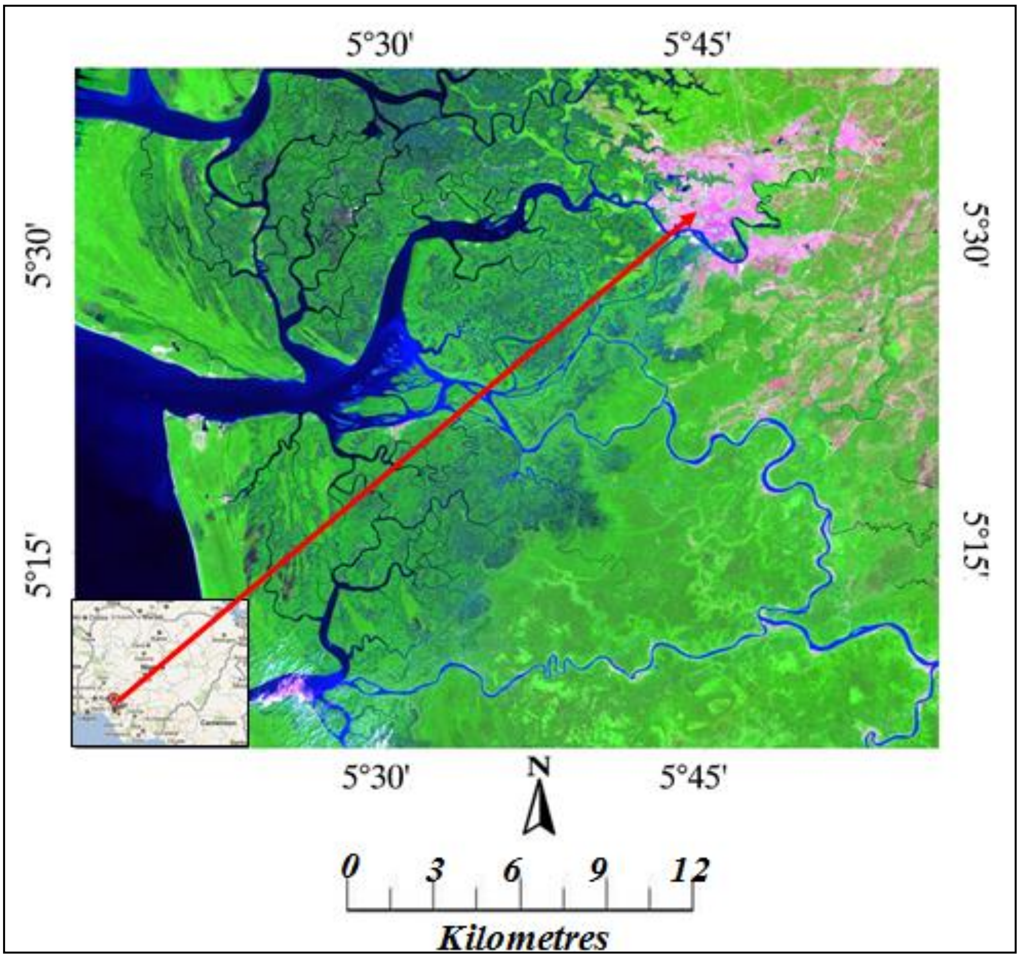


Figure 5.32. Map of the South-western part of the Niger Delta of Nigeria, showing location of Warri

The city expanded rapidly between 1984 and 2001, but the rate of urban expansion is slowing gradually from 2001 to 2011, just like the case study above. The reason for this expansion is understandable. Though, the city has been an important economic city in Nigeria since British colonial era, when it was one of the provincial headquarters established by British, the city grew rapidly due to oil economy growth in the Niger Delta and the establishment of an oil refinery in the city in 1978 (NNPC 2008). A census report by NPC (2006) has established the population of Warri to be about 336,750 in 1991, but this increased to 556,149 in 2006.

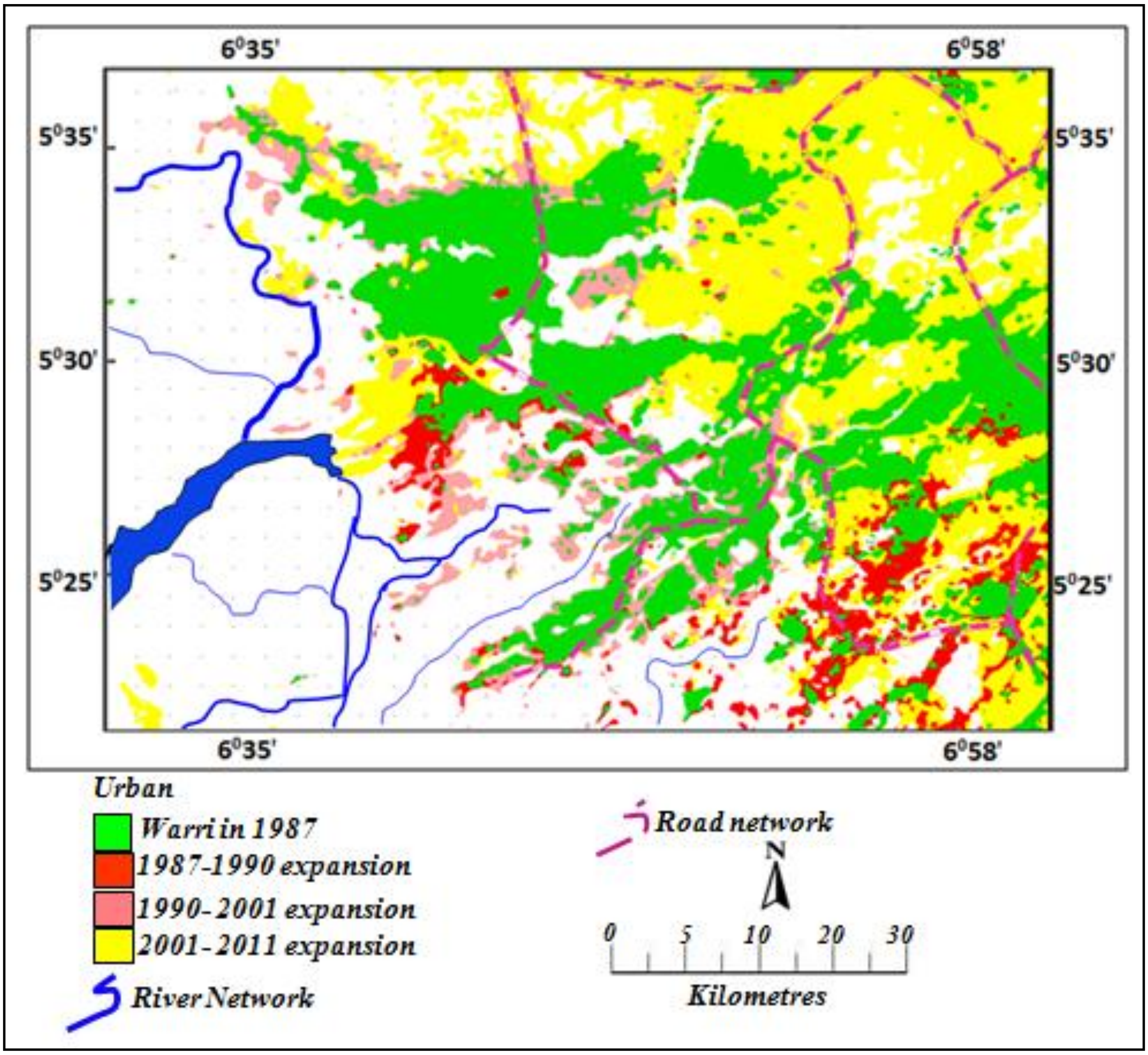


Figure 5.33. Spatiotemporal changes in urban areas around Warri City

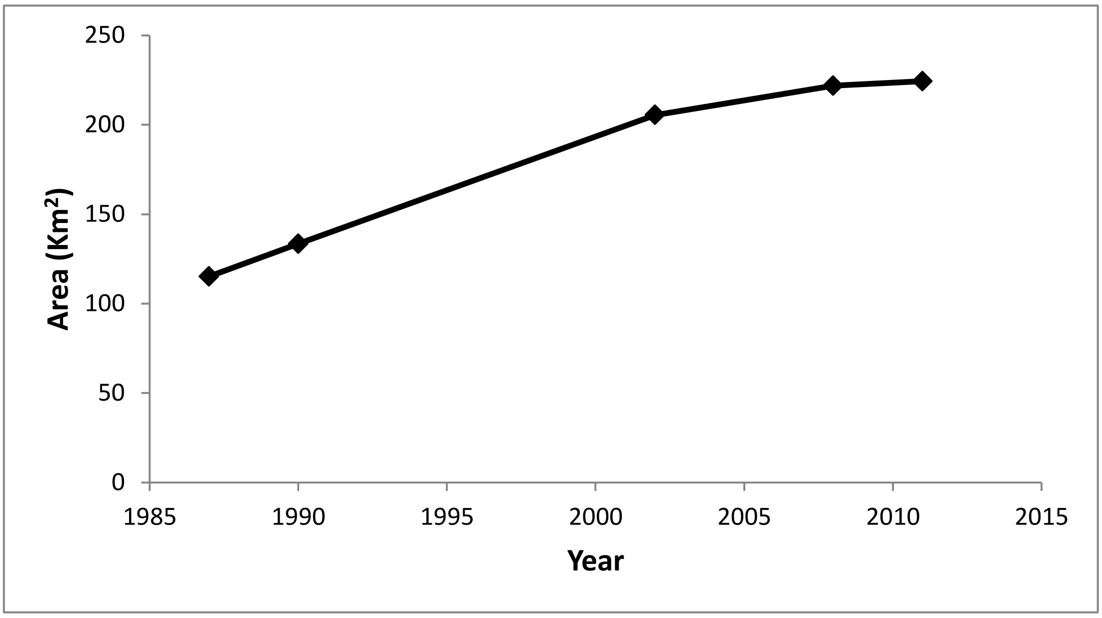


Figure 5.34. Rate of expansion in Warri between 1984 and 2011

5.1.3.6. Urban Expansion in Port Harcourt

Part Harcourt is the capital of Rivers state, the location of the offices of many multinational oil companies operating in the Niger Delta and has developed around the Niger Delta distributary channels (Figure 5.35). Figures 5.36 and 5.37 show the spatial and temporal changes in Port Harcourt between 1984 and 2011. Port Harcourt is also just less than twice the size it was in 1984, expanding from 146km^2 in 1984 to 240 km^2 in 2011 (Figure 5.36),thus, the city has experienced a similar expansion to Warri. It mainly expanded in a south-eastern direction in the 1980's, but then expanded northwards in late 1990s until the 2000s. The population of the city has been increasing since 1956, when Shell moved its south east head office to the city (Ebeku 2006). The initial south-east expansion in 1980s could be attributed to the economic opportunities found where refinery and other oil infrastructures were located (Opukri 2008, Watts 2008). The oil crisis (frequent communal conflicts between oil companies and local people) in the eastern part of the city might have led to the settlement towards the north (Ugoh 2010, Babatunde 2012). Although, there is little information in the literature about the drivers of expansion of this city, it is obvious from the present study that both economic and the physical environment determine the patterns of urban expansion in the Niger Delta. For example, it is clear from Figure 5.36 that there are several main roads in the northern part of the city, while the south and west are locations of several networks of rivers and creeks, thus, there appears to be a clear preferential expansion along main roads. The temporal trend of expansion is really different from the other two cases already discussed, in such that there was a gradual expansion from 1984 to 2004;, a rapid one between 2004 and 2009; and steady increase of expansion from 2009 to 2011. The reasons for these are not clear.

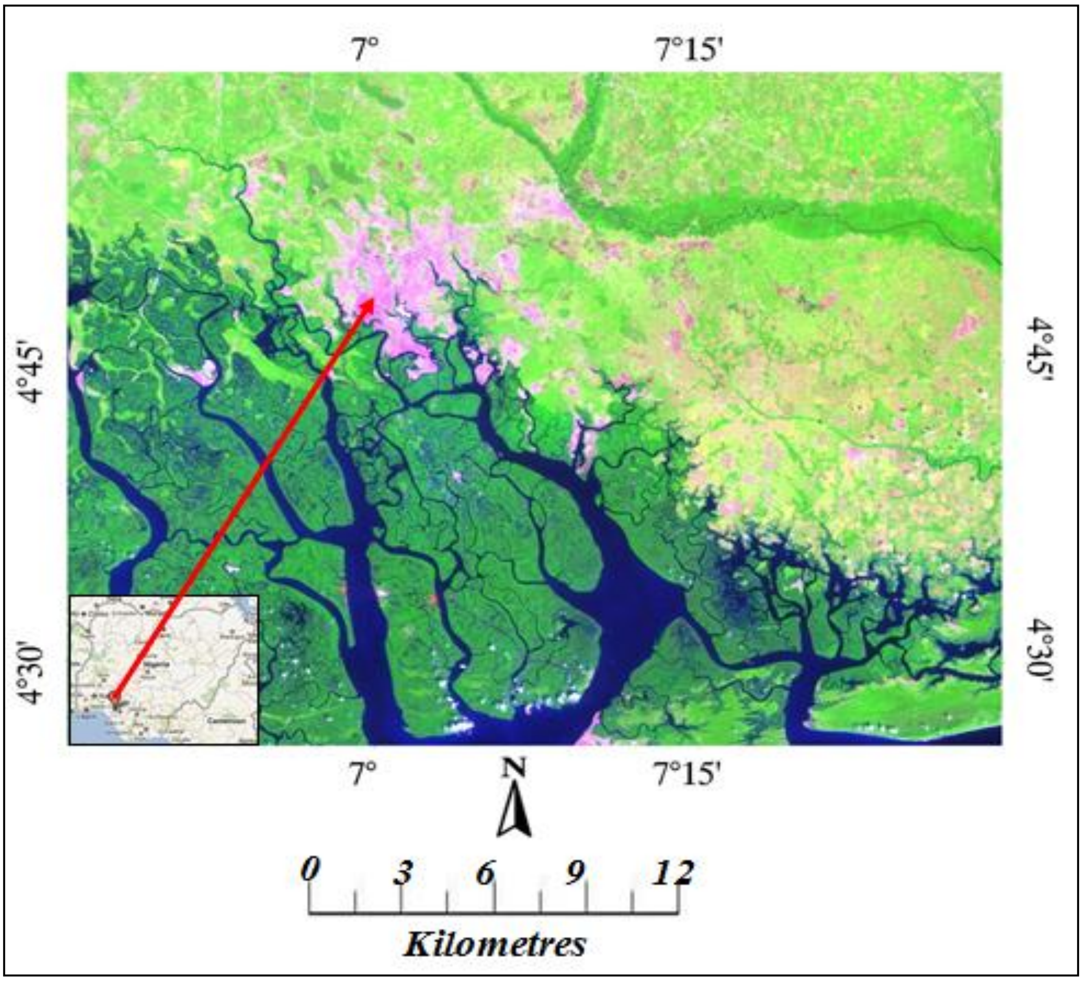


Figure 5.35. Map of the Southern part of the Niger Delta of Nigeria, showing location of Port Harcourt

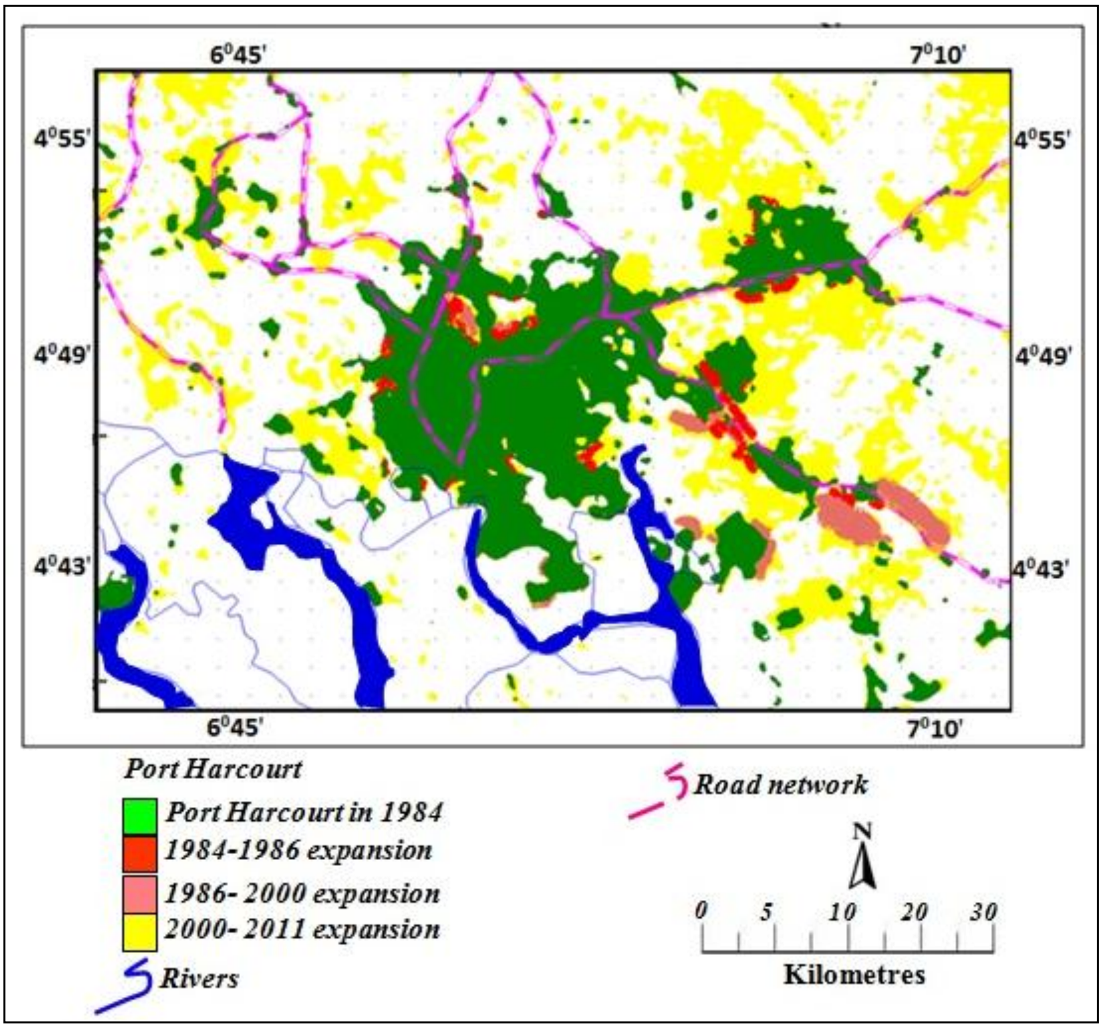


Figure 5.36. Expansions in Port Harcourt from 1987 to 2011

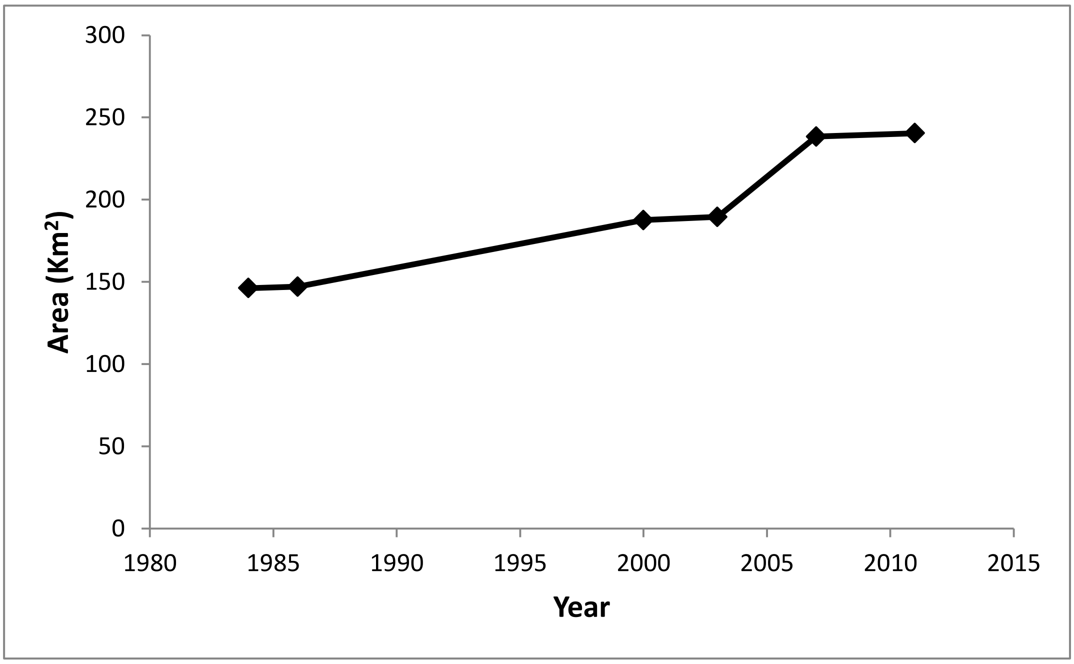


Figure 5.37. Rate of Port Harcourt expansion between 1984 and 2011

5.1.3.7. Expansion in Benin City

Benin City is the capital of Edo state in the western part of the Niger Delta (Figure 5.38). The city has expanded by 51% between 1987 and 2011; and from 179km^2 in 1987 to 320 km^2 in 2011 (Figure 5.40). It is noticeable from Figure 5.39 that the city has expanded in all directions, but predominantly towards southwestern part of the city. Unlike other cities discussed above, Benin City maintained a stable pattern of expansion.

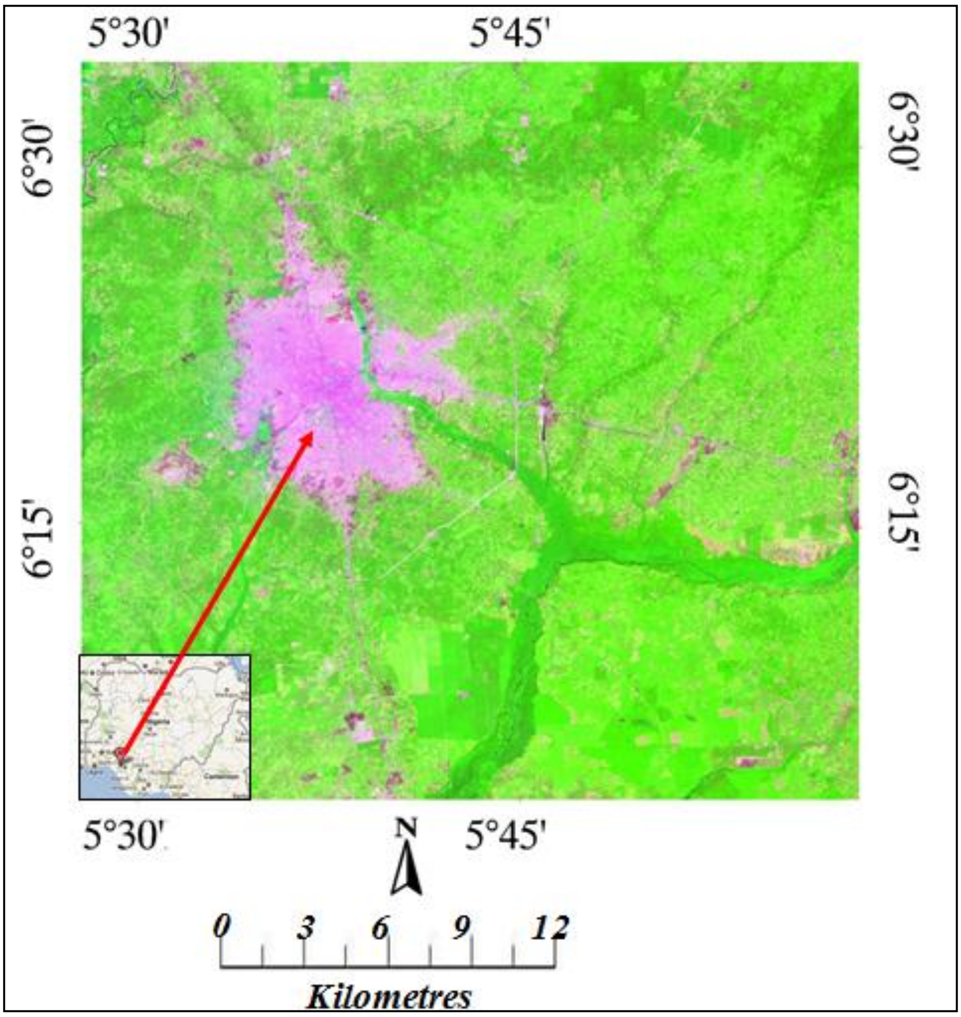


Figure 5.38. Map of the western part of the Niger Delta of Nigeria, showing location of Benin City

Major reasons for this pattern might be due to the nature of the physical environment and low level of oil infrastructure around the city. Benin City is located in a well-drained soil with no creeks (Erah *et al.* 2002), which allows the city to expand in all directions (Figure 5.34), unlike Warri and Port Harcourt, which are bounded by several rivers and creeks. Besides, different from other cities, Benin City is located at the highest point of the Niger Delta, of about 85m above the sea level (Odjugo 2012). These physical characteristics might be responsible for all-round expansion of the city. On the other hand, there is no oil infrastructure located in the Benin City, but the city is known for cultural heritage since the period of colonial master. There are several tourist centres which encourage visitors and aid the economy of the city. The city growth was intensified along the major roads (Figure 5.39), though, there are few recent studies on environmental change around Benin City. A study by Odjugo (2012) have reported that increased in deforestation, resulting from expansion of Benin City, andlow drainage system encourage perennial erosions and flooding, which is the major environmental problem in the city.

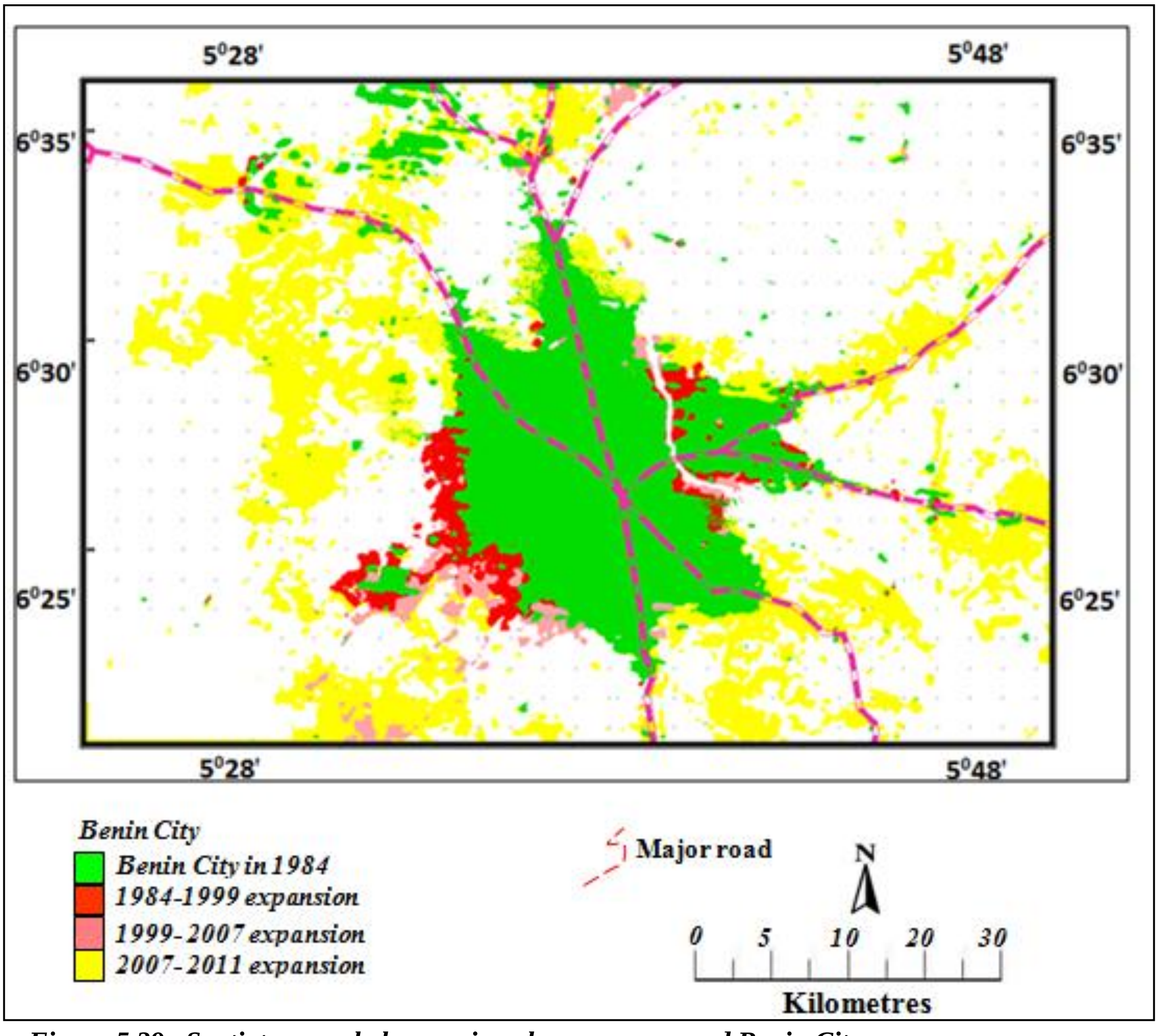


Figure 5.39. Spatiotemporal changes in urban areas around Benin City

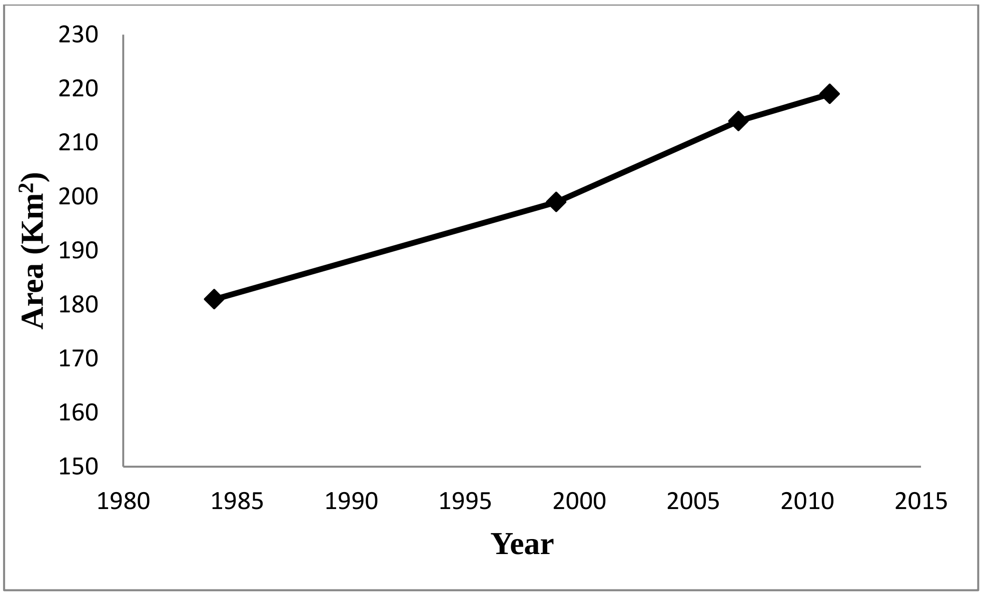


Figure 5.40. Rate of expansion in Benin City between 1987 and 2011

5.1.4. Impacts of Oil Production

5.1.4.1. Mapping of oil spills: A case of Bomu in Ogoniland

Figure 5.41 shows the location of Bomu in colour composite (Figure 5.41A), classification (Figure 5.41B); NDVI Image (Figure 5.41C) and zoomed maps of oil spill location in Figures 5.41D and E, all suggesting that assessing oil spill impact is not possible. Despite the fact that there appears to be a slight oil spill showing up in the NDVI, there are other features that look like oil spills and are not. In the case of ML classification, it is clear from Figures 5.41B and 5.41D that the oil spill is being classified as urban. The reason for this misclassification might be due to poor separability of oils spills and urban obtained during transformed divergent analysis. It is clear from Table 5.13 that all classes have good separability with the exception of oil spill class that has poor separability with urban (TD = 1.455) and farmland (TD = 1.685). Thus, this is likely be the reason for the misclassification of oil spill class with urban, which implies that oil spill has a similar signature as urban and farmland. As a result, Landsat could not separate the area covered by oil spill from that of urban area. In conclusion, both ML and NDVI were unreliable for distinguishing between oil spills and similar features (Figure 5.41), because the methods failed to separate oil spills from the surrounding land surface features.

Three major problems were observed during this analysis. The first was bad weather conditions that prevent assessment of oil spill in Oboolo, as the majority of data available for this location had high cloud cover. Secondly, the low spatial and spectral resolution of Landsat, is a major challenge which makes accurate detection of land surface oil spillage difficult. It is generally impractical to have a specialized high-resolution satellite or aircraft data, because they are very costly, thus made this studyuse Landsat images. Thirdly and finally, the revisiting frequency of Landsat is low, so d when coupled with the problems of bad weather, many oil spills would have been missed.

Table 5.13. Transformed Divergence values for oil spill classification

Mangrove	**Urban**	**Farmland**	**Bare Ground**	**Forest**	**Water**	**Mangrove**	**Oil spill**
Urban		1.976	1.978	1.965	1.998	1.978	1.655
Farmland	1.976		1.988	1.952	2.000	1.956	1.865
Bare ground	1.978	1.988		1.985	2.000	2.000	1.889
Forest	1.965	1.952	1.985		2.000	1.898	1.962
Water	1.998	2.000	2.000	2.000		1.865	1.945
Mangrove	1.978	1.956	2.000	1.898	1.865		1.956
Oil spill	1.455	1.685	1.889	1.962	1.945	1.956	

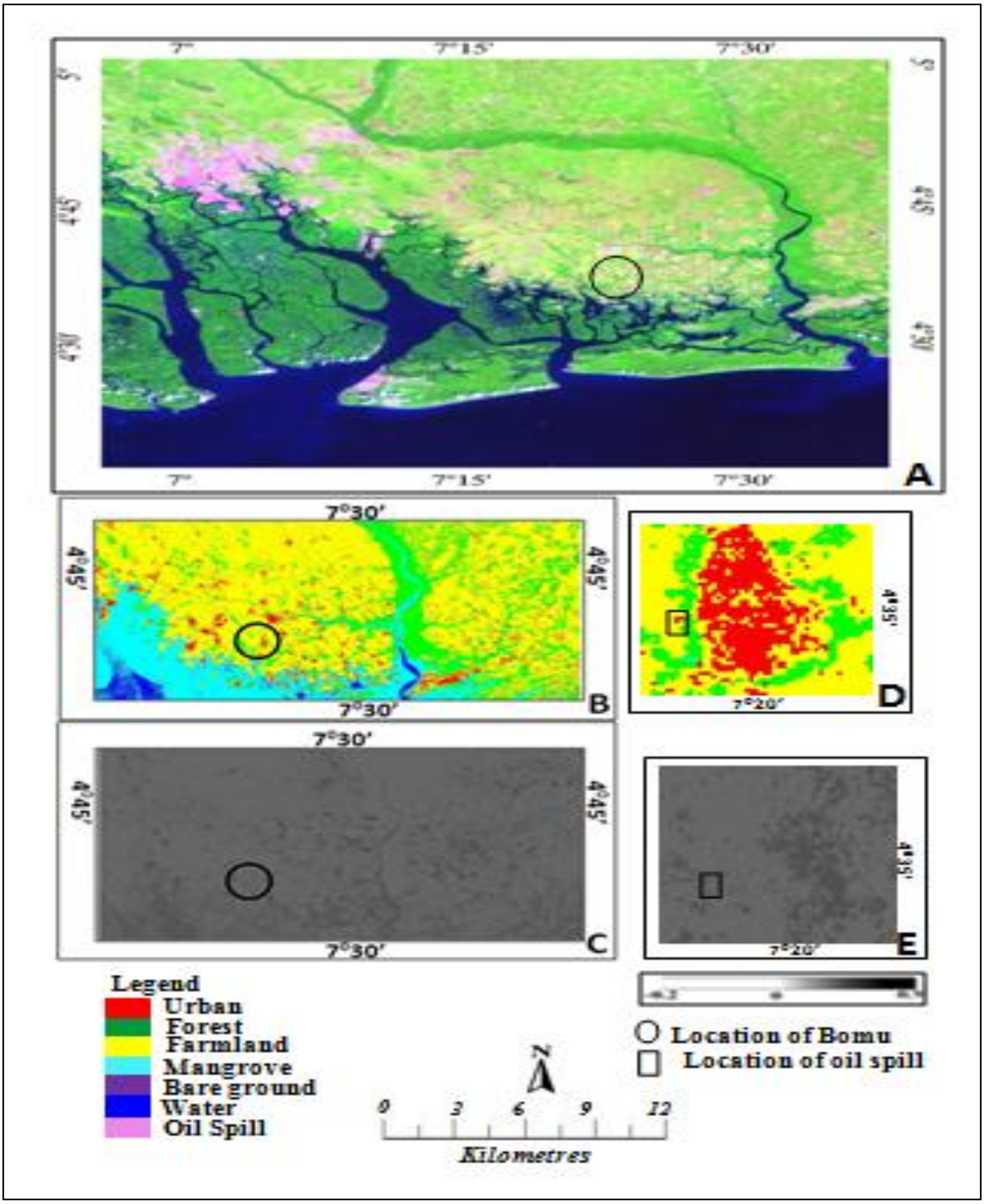


Figure 5.41. Maps showing the location of oil spill in Bomu. A is the colour composite map, B is the classification map, C is NDVI map while D and E are zoomed classification and NDVI maps of Bomu

5.1.4.2. A Case Study of Tsekelewu

Change in landuse resulting from oil and gas exploration is the most pervasive environmental problem in Tsekelewu. Changes around Tsekelewu are presented in Table 5.14, Figures 5.42 and 5.43. Two environmental issues can be noted from Figure 5.42: (1) Rapid destruction of mangrove during 1980s, with very slow regeneration years after and (2) Periodic flooding in years 1999, 2001 and 2011. It was noted in chapter four of this study that years 1999 and 2011 were the wettest years within our period of study. Water on the 1999 and 2011 maps (Figure 5.42), perhaps indicates areas of flooding due to increased rainfall, though the influx of sea water during high tides could also contribute to the large areas of standing water.

During the 1980s, mangrove forest in the region was reduced by 48% (from 200km^2 in 1984 to about 114km^2 in 1987). This decline resulted to an increase in bare ground from 104km^2 in 1984 to 120km^2 in 1987 (Table 5.14). Although, mangroves appear to be regenerating during 1990s and 2000s (Table 5.14; Figures 5.42 and 5.43), this has occurred at a slow rate from 114 km^2 in 1987 to 118km^2 in 1999, 145km^2 in 2001, 192km^2 in 2007 and 198km^2 in 2011 (Table 5.14).

It is apparent from NDVI results that the rate of regeneration observed from 1999 to 2011, has not fully compensated for mangrove loss that occurred during 1980s. For example, mean NDVI values were 0.67 in 1984, but declined rapidly to 0.34 in 1987. Regeneration started in 1990 with mean NDVI values slightly increased to 0.47 in 1999 and 0.51 in 2011 (Figure 5.42).

Table 5.14. Mangrove changes around Tsekelewu from 1999 to 2011

	1984 Km^2	**1987 Km^2**	**1999 Km^2**	**2001 Km^2**	**2007 Km^2**	**2011 Km^2**
Mangrove	200	114	118	145	192	198
Bare ground	104	120	80	40	20	15

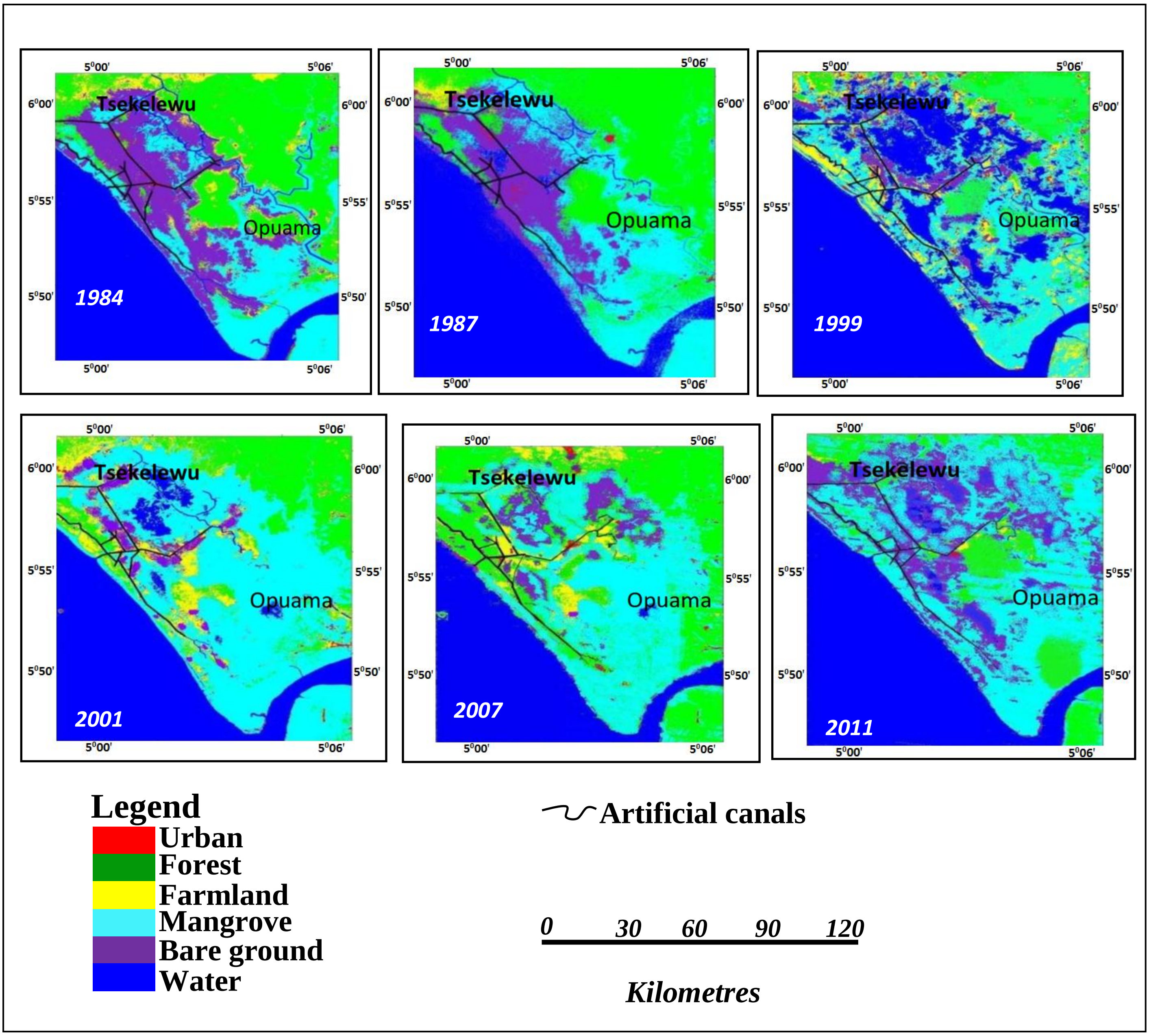


Figure 5.42. Changes in landuse in Tsekelewu oil field from 1984 to 2011

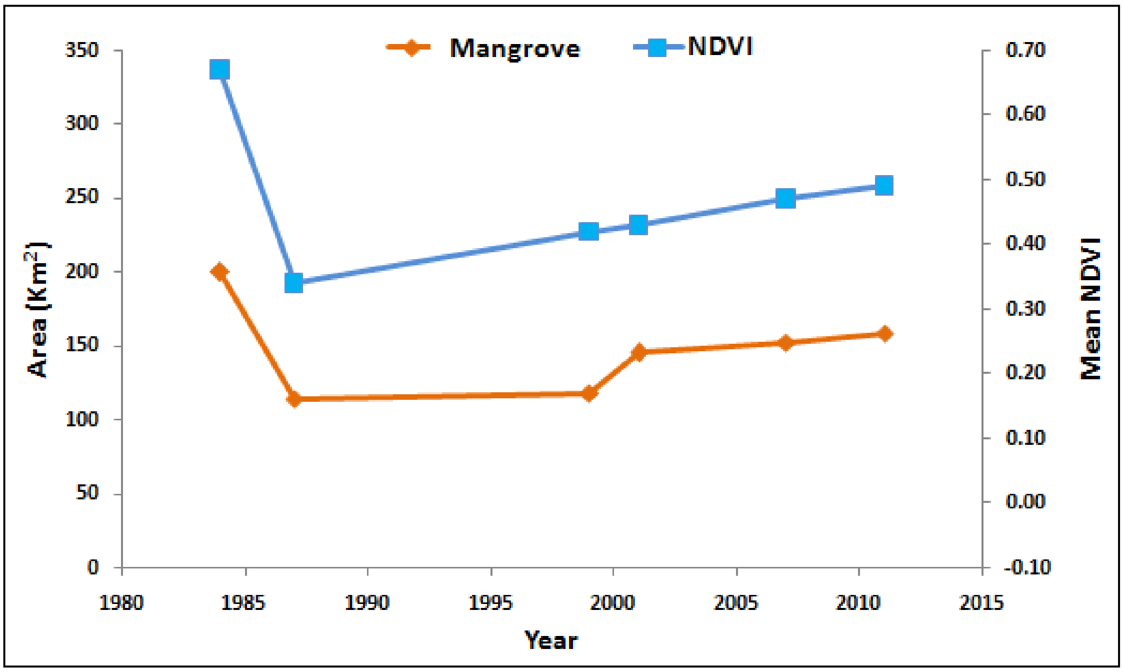


Figure 5.43. Changes in mean NDVI and change in area of mangrove for Tsekelewu oil field

The important factor that appears to be responsible for destruction of mangrove vegetation in Tsekelewu is construction of canal. For example, a network of artificial canals were constructed by Chevron between late 1970s and early 1980s, to link the oil fields they had recently discovered in the region with the Atlantic Ocean for easy transportation of crude oil in barges (World Bank 1995). Unfortunately, the region is the lowest point in the Delta, with some areas below the sea level (Figure 5.44). Construction of the canals (Figure 5.45) links these low regions to the sea, providing a regular inflow of seawater and thus consequent destruction of freshwater mangroves. After fifteen years, vegetation regeneration started with the colonisation of the region by brackish water mangroves.

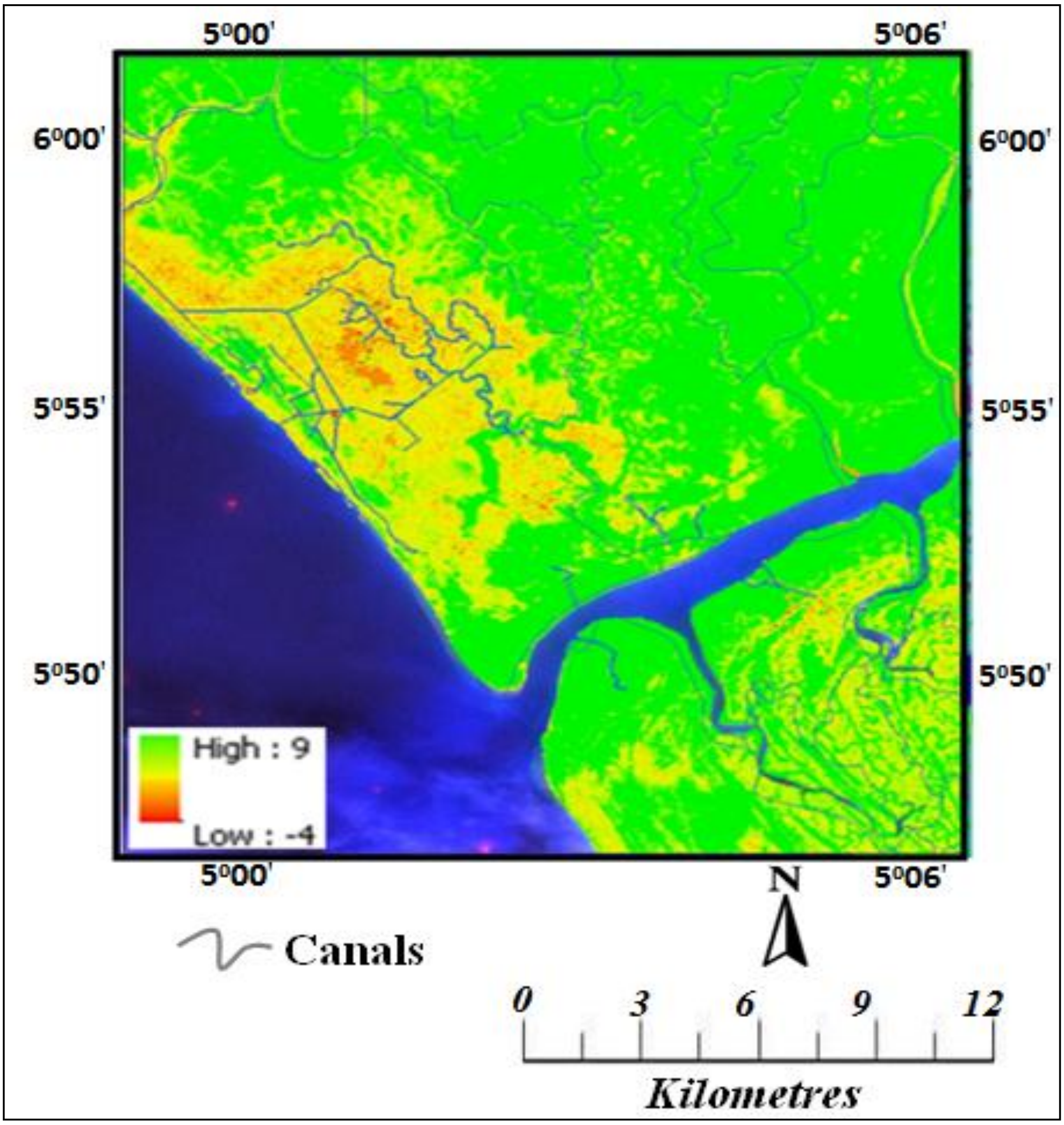


Figure 5.44. Shuttle Radar Topography Mission Digital elevation model of the Tsekelewu region

Figure 5.45. Photo taken during field visit to Tsekelewu on a boat moving over one of the canals

5.2. Drivers of landuse change in the Niger Delta

Two major patterns of change can be observed in the Niger Delta, based on the results presented above. Firstly, forests have been lost, mainly in the lowland rainforest region. Secondly, deforestation expands from the Northern part of the Delta towards the South. In the Eastern part of the Delta, the majority of the forest reserves have been significantly degraded and sometimes destroyed. A higher rate of deforestation is obvious in areas where there is a dense road network (Figure 5.46), thus it appears that deforestation is much intensified along the major roads. From the same Figure 5.46, there appears to be denser road network in the northwest and eastern part of the Niger Delta compared to other regions. This might enhance accessibility to forest and leads to degradation and deforestation. In the centre and southern part of the Delta, at the location of freshwater swamp and mangrove forests, there appears to be a lower rate of deforestation, which is a low density road network; thus accessibility to the forest is limited and this reduces deforestation rates.

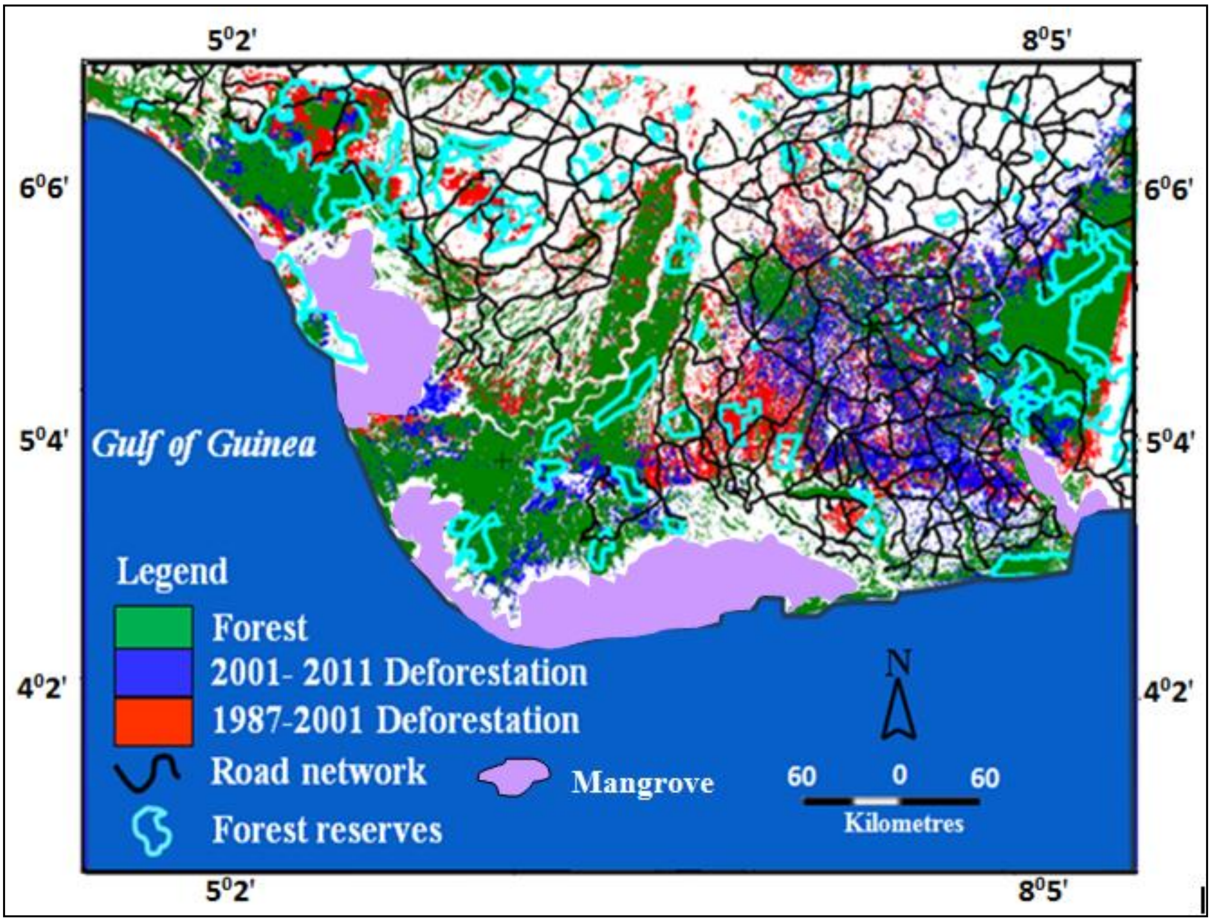


Figure 5.46. Maps showing deforestation around forest reserves and the road network in the Niger Delta over the period between 1987 and 2011

What is apparent from the literature is that the majority of the previous studies conducted in the Niger Delta have claimed increase in population density and lack of political will as the major causes of environmental change in the region (Jike 2004; Aaron 2006; Godstime et.*al*. 2007; Morakinyo and Tooze 2007). Therefore, this study investigates the emerging causes, by examining the correlation between the possible causes of forest destruction and the amount of forest lost. The study uses the results of the landuse change mapping and other available data outlined in chapter four to see if there are any relationship between deforestation, distance to roads, population growth, population density, urban growth and farmland expansion.

5.2.1. Correlation Results: The Relationship Between Landuse Change, Population Density, Deforestation and Distances to the Major Roads

The correlation between urban expansion and change in population density is low (R^2 = 0.02), and not significant, implying that population density has little influence on the rate of urban expansion. Figure 5.48 shows that the highest population density in the Niger Delta is in Imo state, yet it has experienced little urban expansion. The two most rapidly growing cities observed in this study are located in the Rivers state (Port Harcourt) and Delta states (Warri), both states with relatively moderate population density (Figure 5.48). This further suggests that change in population density has little impact on urban expansion. These findings imply that population growth in rural areas is important, and this perhaps explains the result. There appears to be a stronger significant relationship between urban expansion and farmland expansion, but the R2 is low (R^2 = 0.20) (Table 5.15 and Figure 5.47). This implies that urban expansion is not a strong driver of farmland expansion at the scale of the entire Delta, perhaps because urban areas cover such a small part of the Delta, that other more widespread phenomena, such as farmland expansion into forested areas, are confusing the issue. Thus, urban expansion may only locally, on the margin of urban areas, have effects on farmland.

Surprisingly, deforestation and farmland expansion exhibit a low correlation (R^2= 0.13), thus the relationship does not appear to be a direct one, or there are other complicating factors, some of which are already explained to above. There is a higher negative correlation between farmland expansion and distance to road network (R^2= - 0.33), implying that accessibility created by road network might have a large role to play in the change in farmland use in the Delta. There is a stronger negative relationship between change in population density and deforestation (R^2 = - 0.45). This might be due to the fact that in the Niger Delta, less population are located in forests where there is high rate of deforestation, and larger populations in farmlands and urban areas. This implies that some of the human activities that may contribute to forest loss are driven by factors that have little or nothing to do with local population density. A study by Marcoux (2000) has earlier noted that there cannot be a dense forest cover where there is high population density, and vice versa, thus an inverse or negative correlation between population density and deforestation is expected.

Marcoux further stated that if the regions had little forest cover and a high population at the beginning of analysis, populations may increase rapidly without deforestation, thus an increase in population density does not necessarily result in a proportional increase in deforestation. Accordingly, it appears that the rapidly declining forest in the Niger Delta is not directly due to increase in population density. A slightly stronger negative correlation exists between distance to major roads and deforestation (R^2 = - 0.46) (Table 5.12), which appears that it is accessibility to forests created by expansion of the road network, that gives loggers and subsistence farmers access to previously unaffected forests, and that explains best the deforestation in the Niger Delta. This implies that accessibility to forest reserves may well have contributed to their demise, and supports the theory that the only thing that has saved Gilli-Gilli reserve so far is its inaccessibility.

Table 5.15. Correlation of landuse change with population density and distance from major roads.

Driver of change	Urban Expansion (R^2)	Farmland Expansion (R^2)	Deforestation (R^2)	Change in Population Density (R^2)	Distance from Major Road (R^2)
Urban Expansion	1.00	0.20	0.05	0.02*	-0.04*
Farmland Expansion	0.20	1.00	0.13	-0.28	-0.33
Deforestation	0.05	0.13	1.00	-0.45	-0.46
Change in Population Density	0.02*	-0.28	-0.45	1.00	-0.03*
Distance from Major Road	-0.04*	-0.33	-0.46	-0.03*	1.00

* ***Correlation not significant at 0.05 level.***

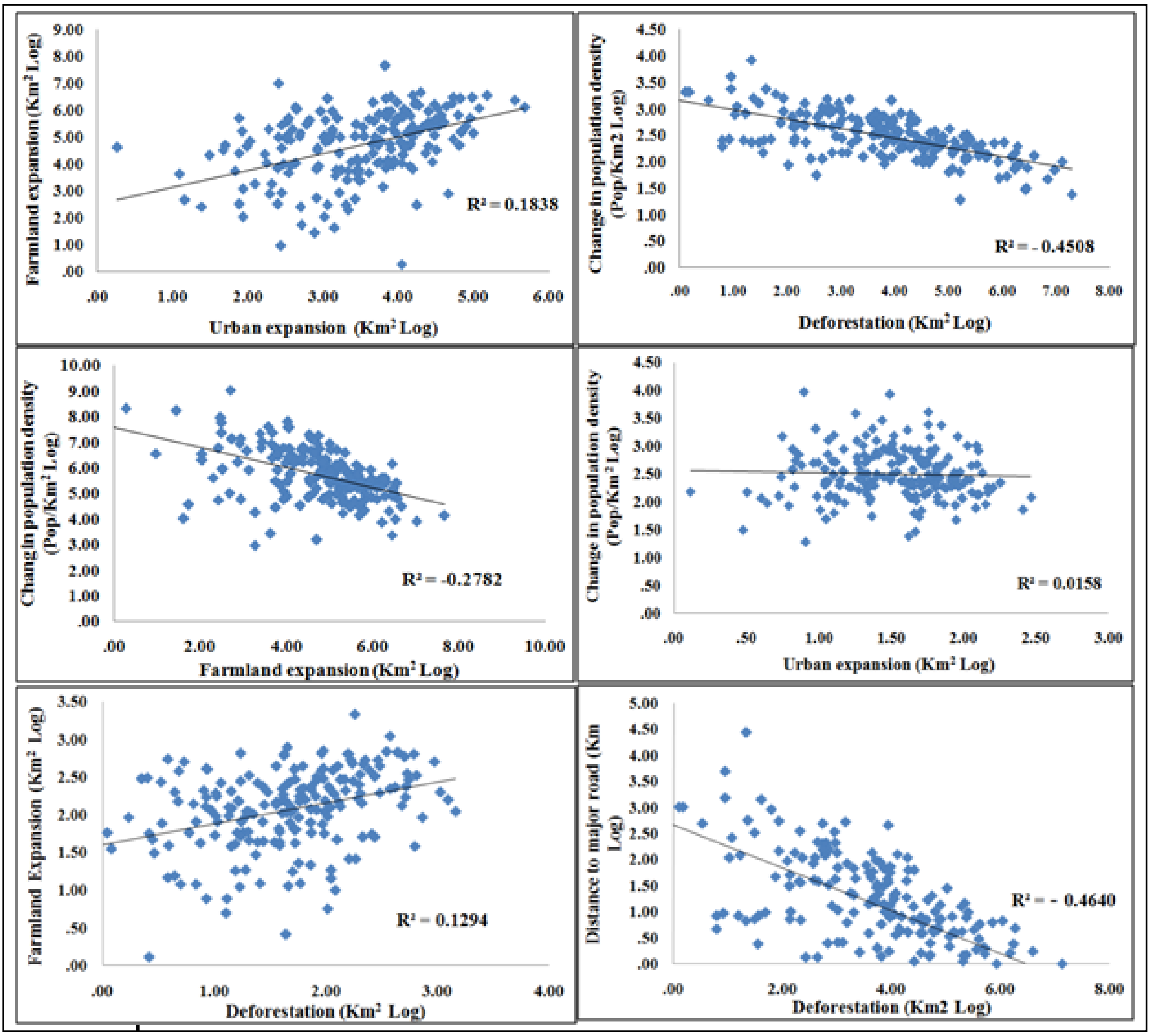


Figure 5.47. Relationship between deforestation, population density, urban and farmland expansion and distance to major roads in the Niger Delta. The scatter graphs are calculated in loglines

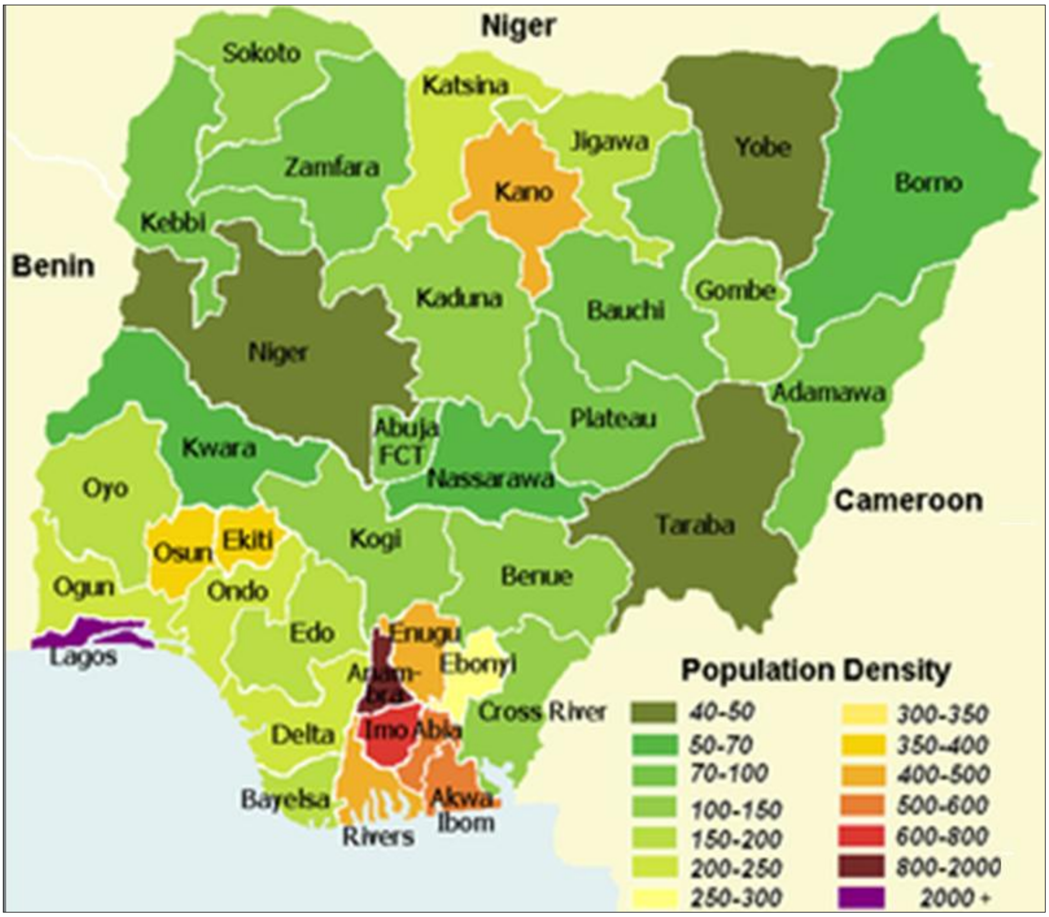


Figure 5.48. Map showing population density of Nigeria as at 2011 (Source: http://en.wikipedia.org/wiki/List_of_Nigerian_states_by_population)

Generally, correlation results reveal two major points: (1) that growth in population has no direct role to play in deforestation, at least in the short term (2) declining in forest in the Niger Delta appears to be due to increase in farmland, and more importantly, accessibility by roads (Table 5.12 and Figure 5.47). There seems to be a very strong negative relationship between the distance from major roads (accessibility) and rate of deforestation. From Figure 5.46, it is also clear that the rate of deforestation is extremely high at a closer distance to major roads, while forests that were very far from the major roads appeared less disturbed. These values thus imply that accessibility to the major forest reserves contributed to higher percentage of deforestation in the Niger Delta.

5.3. Results of Social Research: Societal Implication of Environmental Change on the Delta

The results of social research are presented in two ways: Qualitative and Quantitative results. Results from questionnaires are reported under quantitative heading, while interview and focus group findings are reported under qualitative results. These results illustrate the societal implications of landuse change; deforestation; farmland expansion in the forest reserves; and the social and health impacts of oil production and its infrastructures.

5.3.1. Results from Interviews and focus group discussions

5.3.1.1. Societal Implications of Landuse Change, Deforestation and Farmland Expansion within Forest Reserves

This section reports the results of focus groups and interviews methods used in this study. Table 5.16 summarizes the key responses from focus group discussion in different locations of the Niger Delta. It is clear that most of the people that were involved in the focus group discussion in Okitipupa said that "urban expansion around Okitipupa has great impacts on their farmland". The main argument of participants was that "urban expansion is a necessary evil". The majority of the people said this is because urbanisation is one of the signs of economic prosperity in their communities and also, two of these people took us to their former farmland, which is now taken over by built structures to demonstrate their claim. The remaining minority argued that "urban expansion is necessary for both social and economic development of their communities, and that expansion of built-up areas toward their farmland is part of the price they have to pay for economic prosperity". They said that many people in "the local community exchange their farmland for huge amount of money offered by the estate builders". When questioned about deforestation, majority of the participants agreed that trees have been removed from the nearby Ajagba Forest and this has led to reduction in the wildlife that they see around them. They even said that "it is very hard to find natural matured trees in the vicinity". They perceive that the "majority of the matured trees in the forest reserves have been removed for timber trade or destroyed by farmland or urban expansion".

Similar responses were obtained during the focus group discussions in Okomu. Many people who participated agreed that “deforestation has been on the increase in the Okomu forest reserve for the past thirty years, and that this has great impact on wildlife” (Figure 5.49). Some participants argued that “Okomu forest is their heritage, and farmland cultivation within it, is their major source of livelihood”.

Figure 5.49. Photo taken during focus group discussions, showing the relaxed and informal nature of the session

In general, the results from focus group audio records show that deforestation has been a major environmental problem in Okomu Forest Reserve. Many people said that the Oil Palm Plantation Company (located within Okomu), cut down trees with a sawmill located within the Oil Palm Plantation Company premises, thus lending support to this view. Many of the participants are familiar with the forest and have visited the plantation of the Oil Palm Company. They said that “some areas of the forest reserve have been taken over by Oil Palm Company and are now covered with oil palms”. The majority of the participants of the focus group also said that the “lack of enforcement of the environmental laws (by State government), on the operation of Oil Palm Company located within the forest reserve, is one of the fundamental causes of the failure to protect Okomu forest”.

Table 5.16. Key responses from the respondents of focus group discussions on landuse change and its consequences on wildlife

Location	Changes in the community in the past thirty years	The causes of the changes	The consequences of landuse changes on wildlife	What can be done to reduce forest degradation and environmental degradation in the Niger Delta?
Okiti-pupa	Urban expansion and deforestation.	Urbanization. Economic/infrastructural development such as road construction. Intensive farming activities.	Loss of habitat for wildlife. Reduction in the of number wildlife.	Sustainable development should be encouraged.
Okomu	Deforestation and degradation of forest reserves.	Illegal and uncontrolled logging.Poor management of the forest. Many people perceive that the Oil Palm Plantation Company (located within Okomu) cut down trees in the reserve.	Biodiversity loss in the protected areas in the Niger Delta.	Illegal logging should not be allowed in the forest reserves.
Tsekelewu	Oil pollution and pollution from salt water via artificial canals constructed by Chevron Oil Company.	Regular flooding of sea water into freshwater zone, affecting ecology of wildlife.	Depletion and loss of habitat for wild animals. Fishing grounds usually flooded with salty water.	Government should be more effective in monitoring the operation of oil Companies.
Eket	Oil pollution and contamination of drinking water from oil production activities. Unsustainable exploitation of mangrove in the region has been the significant feature of environmental change.	Pollution from oil production, contamination of water	Uncontrolled hunting of wildlife has led to reduction wildlife. Endangered animals include: Sclater's guenon and white-throated guenon, red colobus monkey.	Federal government and forest stakeholders should work together for better protection of forest reserves in the Delta.
Oboolo	Oil pollution and contamination of drinking water from oil production activities of multinational oil companies.	Pollution from oil production, contamination of water.	Animals that could not tolerate oil pollution have gone extinct.	Compensation of those people affected by oil pollution. Environmental laws should be properly enforced.

5.3.1.2. The Perceptions of Environmentalists

Table 5.17 shows the key responses from environmentalists, forest reserve staff and local people. It is evident from the table that all interviewees believe that deforestation and other environmental changes have been increasing in the forest reserves in the Niger Delta. For example, a member of the Nigeria Conservation Foundation (NCF) stated that: “over the past three decades, forest reserves in the Niger Delta have been witnessing rapid increase in deforestation resulting from farming activities within the forest reserves in the Delta”. He also said that “based on my experiences, introduction of the Taungya system of farming within the forest reserves in the Delta has been the major means of forest degradation in the region”. The Taungya system was proposed as one of the drivers of deforestation noted in the remote sensing results.

Though, NCF advocates forest conservation, not only in the forest reserves within the Niger Delta, but also for all forests in Nigeria. The member of NCF also claimed that the” introduction of Taungya system in Okomu is like a cancer, which encourages rapid degradation of forest in the reserves”. However, one of the arguments of one of the staff of the forest reserve is that there is no way of controlling or discouraging the farmers, who are not interested in planting trees, but could rather practise permanent cultivation of the same piece of land again and again. On the other hand, the member of NCF thought that farming within the forest reserves must be discouraged to eradicate widespread illegal farming and commercial loggers inside the reserves.

Table 5.17. Key responses from the respondents: results from interviews of environmentalists, forest reserve staff and local people

Respondent	Changes in the forest reserve over the past thirty years.	The major causes of forest change	Consequences of landuse change on the wildlife	What can be done to eradicate or reduce forest degradation and environmental degradation?
Member of Nigeria Conservation Foundation (NCF)	High	Accessibility to forest created by oil infrastructures such as road networks.Illegal logging: both commercial logging and firewood collection by local people.Farming activities within the forest reserves	Uncontrolled hunting of wildlife has led to reduction of wildlife. Endangered animals include: Sclater's guenon and white-throated guenon, red Colobus monkey.	All forest reserves in Niger Delta should be constituted as strict nature reserves to prevent illegal logging.Forest policies need to be reformed.Farming within the forest reserves must be discouraged to eradicate widespread illegal farming.
Director of Institute of Ecology of Obafemi Awolowo University, Ile-Ife, Nigeria	High	Road network and digging of canals for transport of timbers. Poor management plan of forest reserves in the Delta.Illegal and uncontrolled logging.Unenforced environmental laws. Several protected areas in the Delta have been degraded due to agricultural land use within forestry reserves and other forms of deforestation.	Loss of biodiversity in major protected areas. Populations of the endangered animals are: Sclater's guenon, Chimpanzee, Drill, Grey necked and Niger Delta pigmy hippopotamus.	Sustainable developm ent which encourages environmental protection and sustainable oil exploitation. Illegal logging should be stopped in the forest reserves. Proper enforcement of forest and other environmental laws.
Manager of Okomu forest reserve	High	Clearing of the forest for farmland. Illegal and uncontrolled logging.	Biodiversity loss in major protected areas in the Niger Delta. Endangered animals include: Chimpanzee, Red colobus monkey, Sclater's guenon an White-throated guenon.	Okomu and other forest reserves should be given proper protection to prevent oil plantation and other farmland encroachment.
A member of Staff of Bayelsa	High	Uncontrolled increase in population of the villages around the	Depletion and loss of habitat for wild animals, perhaps	Forest laws should be enforced.

National Park		park.Insufficient funding for park protection and monitoring activities. Large-scale illegal logging and uncontrolled hunting of wildlife.	endemic species Animal species go extinct.	
A member of the Staff of Umon Ndealichi forest reserve	High	Firewood collection for cooking and warming homes. Illegal logging and uncontrolled hunting of wildlife.	Reduction of the number of wildlife in the park.	Illegal loggers should be bound through proper environmental law enforcement
Local people	High	Large-scale illegal logging. Unsustainable firewood collection for cooking and warming homes. Forest clearing for farming. The managers of forest reserves are incapable to appropriately enforce the laws guiding the exploitation of forest reserve resources.	Recent reduction in animal catching during hunting. The following animals used to be abundant in the forest, but now their numbers have reduced: Niger Delta red colobus monkey, Crested genet, Sclater's guenon, Angwantibo, Grey-necked picathartes	Federal government and forest stakeholders should work together for better protection of forest reserves in the Delta.

The results from this social survey also show that illegal loggings; and commercial and firewood collection by local people, are not the only factors that drive the depletion of forest resources in the region, but accessibility created by oil production infrastructure such as road networks and artificial canals constitutes a major driver of deforestation in the Delta. This creates accessibility means for local people to log the forest. The member of NCF furthermore said that "over 80% of rural dwellers in the Niger Delta depend on wood from the forest for their domestic cooking, thus, they contribute significantly to the problem of deforestation in the region". Besides, another factor of deforestation is farmland expansion and economic development actively encouraged by the community leaders and local government administrators. The member of NCF also said that the "lack of political will towards proper forest laws and their enforcement, including political instability and corruption, and different forms of mismanagement of the forest reserves constitutes the major factor resulting in degradation in many of the forest reserves in the Delta".

Similar responses were received from the Director of the Institute of Ecology of Obafemi Awolowo University, who stated that the forest reserves in the Niger Delta are "not properly maintained, while management plans are abandoned". He also argued that "deforestation is not only peculiar to the Niger Delta region, but the whole country has recently witnessed an absolute disregard for the forest, and local people are enormously depending on forest resources". This makes the forest in the country vulnerable to wood collection since forest laws are not effectively implemented. The Director also claimed that "the long term pursuit of forest policy objectives and forest legislation, without ensuring effective enforcement because of unreliable forest management is a major problem", which still allows illegal loggers and farmers to keep entering and operating in the forests.

All the environmentalists interviewed have stated that the major problem facing wildlife conservation in the Niger Delta is the increasing rate of habitat loss resulting from commercial logging, expansion of farmland within and around the forest reserves and pressure from a rapidly increasing population. This has affected wildlife within the Niger Delta and the ecology of the forest, leaving only remnant populations of wildlife in some protected areas.

5.3.1.3. What the Members of Staff of the Forest Reserves Felt

The manager of Okomu Forest Reserve argued that “illegal logging, clearing of the forest for plantation and other agricultural landuse by local people around the forest is one of the factors of forest degradation in the reserve”. The manager further stated that what makes the situation in the Okomu more complicated compared to other forest reserves in the Delta is “large-scale illegal logging, allocation of some parts of the forest to Oil Palm Plantation Company and uncontrolled hunting of wildlife, which eventually has a great impact on biodiversity in the Delta region”. He said that the illegal loggers are typically armed with weapons when coming to log the timber during the night, to attack forest officials and any other people who want to hinder them in their illegal activities.

During our visits to the forests, we observed several trucks belonging to illegal loggers carrying logs after midnight. We also met few trucks on the way around the reserve during the day carrying logs of timber (Figure 5.50). We followed one of the trucks carrying the logs to determine the destination of the logs, though our main means of transportation during the field work was motorcycles. The destination turned out to be nearby Benin City, where there were several saw mills. The manager said that “the loggers are being sponsored by some timber traders in the cities around the forest reserve; many of these traders are rich and influential people in the cities who arm the loggers with weapons”. We also observed several areas being deforested within the reserve, especially areas close to the Okomu Oil Palm Company (Figure 5.51). Previous studies have reported that the Oil Palm Company within this forest reserve has been involved in illegal logging and several trees have been removed due to the activities of the company (Atakpo and Ayolabi 2009; Ibaba 2010; Onojeghuo and

Blackburn 2011). All efforts were made to interview the manager of the Oil Palm Company, but he said that he did not have time for us. He thus declined to be interviewed.

The staff of other parks such as Umon Ndealichi forest reserve and Bayelsa National Park argued that people of the Niger Delta depend on forest resources to generate much needed revenue and fuel for domestic cooking. Coupled with this problem, according to a staff of Bayelsa National Park, “it is rapid oil infrastructural and economic development, that has led to continuing high rates of uncontrolled forest degradation and natural resource exploitation in this region”. The staff of Umon Ndealichi forest reserve further argued that these factors have “led to highly fragmented wildlife habitat; and park protection and monitoring are deficient in many forest reserves in the Delta, due to insufficient funding”. He also pointed out that population of the villages around the park has increased over the years, and the “majority of rural people are poor, who depend on forest resources for their livelihood”. The man also said that the rapid increase in the population of people around the forest reserves encourages expansion of agriculture, since the majority the local people are agrarian. Coupled with these factors are fuel wood collection; pole and commercial timber harvesting; and oil and gas exploration, the consequences of which include biodiversity loss due to destruction of wildlife habitat.

The staff of Bayelsa National Park however, claimed that Bayelsa National Park is “relatively less disturbed compared with other forest reserves in the Niger Delta”. This is because the forest reserve is located in a freshwater swamp forest which makes it less accessible. This statement helps to explain the major findings from remote sensing analysis that forest reserves located in the lowland rainforest are highly degraded compared to those located in the freshwater swamp forest.

To protect the forest reserves and national parks, the staff of forest reserves argued that forest conservation policies and all of the environmental legislation of Nigeria need to be reformed. Reformation must include implementation and enforcement of all the legislations addressing deforestation. Additionally, the staff of Bayelsa National Park suggested that "such reform must involve the prevention of illegal logging and encourages reforestation in all forest types, including both indigenous and exotic species in the Niger Delta.

Figure 5.50. From top left clockwise: the insignia at the gate of Okomu National Park; the researchers travelling within the forest reserves by motorcycle; image of vans carrying logged timbers from the reserves.

What is clear from the interviews of the officials of the forest reserves is that all of them stated that insufficient funding for parks protection and monitoring activities, is the major hindrance to proper management of the forest reserves, not only in the Niger Delta region, but the situation is the same for all forest reserves in the country, Nigeria.

Figure 5.51. The researchers taking samples and validating the classification maps

5.3.1.4. Local People's Perceptions of the Landuse Change and Forest Degradation in the Delta

Most of the local people interviewed pointed out that the rate at which local people cause landuse change and deforestation in the Niger Delta cannot be compared with massive deforestation from commercial logging. They argued that local people enhance the conservation of forest reserves by encouraging their people to preserve forest for traditional purposes. They similarly affirmed that older people of their communities are concerned regarding the rapid removal of exotic trees in the forest around them, and disappearance of much of the wildlife. To the people, the environment is seen more as their heritage, rather than something to be destroyed. They believe that when they protect forests. they protect their source of traditional medicine. They also claimed that social values and a culture of good environmental management and protection are repeatedly passed down to their younger people. When we asked them questions relating to illegal logging and firewood collection by local people, they blamed illegal loggers from outside the community, pointing out that "they use the firewood collection as a result of need for fuel by local people, not for greed or for profit making as in the case of other illegal loggers". An hunter,about 65 years of age, in one of the villages told us that one of the effects of logging is that "some animals - such as Sclater's monkey and Leopard have become extinct in the area, as the majority of the species were abundant forty years ago"(Figure 5.52). Local people also requested that the Nigerian Government should make alternative fuel available for their domestic cooking; this would reduce the rate of wood collection in the forest.

Figure 5.52. Photo of a researcher discussing with a hunter during field work in Okomu

Correspondingly, one of the local people interviewed in Okomu argued that "the intensity of impacts of firewood collection on forest reserves is very little, compared to the rate of illegal logging, clearing of forest for oil production, oil palm plantation and urbanization". The local leader (Figure 5.53) is of the opinion as well, that the web of drivers leading to deforestation in the Niger Delta is complex, and that the impacts of firewood collection are small. They believe that most of the fuel wood, which local people collects from the forest, are "dead branches which fell from the tree". All the interviewees also said that "accessibility created by socio-economic and oil production infrastructures encourage illegal settlements by the rapidly growing population, and enable illegal loggers to penetrate into the forest reserves in the Delta".

Figure 5.53. The researcher with the local village leader (to the right) during field work in a village around Eket.

5.3.1.5. Local People's Perceptions on the Impacts of Oil Production and Its Infrastructures on the Delta

In this section, results of focus group discussions on the impacts of oil production on the major oil- producing communities of the Delta are presented. The results indicate that pollution from oil production; contaminations of water resulting from flooding of sea water into freshwater; and unsustainable exploitation of mangrove in the region have been significant features of environmental changes in the Niger Delta. For example, it is clear from Table 5.13 that the main environmental problem mentioned by most of the people who participated in the focus group discussions in Tsekelewu was the regular oil contamination of streams and rivers, and flooding of sea water into freshwater ecosystem. They said that "these problems started when artificial canals were developed by Chevron Oil Company operating in the area". We were led to some locations of perennial inflow of sea water, and they said that “numerous species of vegetation had died, because they could not tolerate salt water” (as shown in Figure 5.54).

The majority of the participants also said that this environmental problem “affects their livelihood, salinizing their farmland, and making fishing difficult, because their fishing ponds are often flooded with salty water”. Likewise, participants of the focus group discussions also said that “failure to implement environmental laws, and the unconcerned attitudes of multinational oil companies in the Niger Delta, are the main causes of the environmental problems in the region”. Majority of the participants of the focus group discussions in Eket and Oboolo also complained of the regular oil pollution of rivers, which is their main source of drinking water (see Figure 5.55), which made diarrhoea, skin irritation and stomach-ache be the major health problems they experience, resulting from the oil pollution.

It was also clear from the focus group discussions that the local people in the community have “long complained that pollution from oil production has devastated fishing and farming, which are the main occupations of people in the region”. During the focus group discussion with the local people in Eket, the majority of them confirmed the effectiveness of the efforts of their local governments in reducing the impacts of environmental change in their area. Unlike the responses from other communities, the participants in focus group discussions in Eket claimed that they receive “some financial assistance from state and local governments on their oil affected farmland, although oil companies do not help them”. However, the participants in other regions argued that “state and local governments’ officials offer little compensation for poor affected local people”. Interestingly, two individuals opposed the majority with the view that their local leader does respond well and helps people in the community who have health problems. However after the meeting, when some people had left, many people came to us confidentially to say that those two pro-leader members work for the leaders. They told us that they believed that the two individuals came to the focus group meetings to support the leaders.

In contrast, the majority of participants in Oboolo agreed that governments and village leaders' responses to health problems are not encouraging. Unlike Eket, the participants in Oboolo stated that they do not receive any support from governments and leaders. The reasons behind inequality of supports received from governments and leaders of the different communities are not clear.

Problems of security and oil piracy also came up in the discussions. Participants noted that "kidnappings and piracy have been increasing since the government crackdown on oil theft began in 2005". Conversely, several reports published by oil companies blame oil thieves and other militant groups for the majority of oil spills and the resulting pollution. The majority of participants argued that the infrastructure of multinational oil companies (e.g. pipes) and oil facilities in their communities are difficult to defend. They also noted that "in the Niger Delta, oil has impacted the environment even more than the situations in the Gulf of Mexico in USA, which recently received international attention and publicity".

Overall reflections on the focus group meetings in all the communities affected by oil pollution showed that most people are aware of the fact that the impact of oil production on their health is significant. The majority of the people noted negative impacts of pollution from oil on their health. Most people also think that the federal government "does not do enough to reduce or eradicate these environmental health problems, coupled with the fact that oil companies also are not ready to help". The general suggestion from participants was that government allocations should be "spent on projects that focus on health services and safe drinking water in the Niger Delta". They also suggested that governments should provide supports to NGOs for an independent Environmental Impact Assessment (EIA) of the Niger Delta. In every location where focus group discussions were conducted, the general argument of participants is that "the environmental impact compensation should be distributed transparently in a manner that benefits affected people in the communities especially the poor people who were affected by the environmental changes, rather than to benefit the traditional leaders or politicians". They said that "many of their leaders and politicians are corrupt, and use public money for themselves and their family benefits". The results from focus group discussions thus suggest that communities in the Niger Delta should partner with reputable NGOs who have demonstrated commitments to their communities in reducing environmental degradation, especially where federal and local governments' supports are lacking. The results also imply that the government funding needs to go through NGOs for effective supports for people affected by the oil pollution.

Figure 5.54. Photo taken during field work. One of the locations of inflow of saltwater hinterland. The signpost in the photo indicates that the local people should take caution of contaminated water from inflow of saltwater.

Figure 5.55. Photo taken during field work. Water pollution from inflow of saltwater hinterland

5.3.1.6. Perceptions of Health Professionals on the Environmental Change

Table 5.18 presents the responses of the health professionals interviewed in Tsekelewu, Eket and Oboolo. Health professionals (Doctors and Local Nurses) confirmed the regular occurrences of stomach-ache and skin irritations as the health problems associated with oil pollution (Figures 5.56, 5.57 and 5.58), as tabulated in Table 5.18. The nurse being interviewed in Tsekelewu said that oil production in the communities has caused tremendous environmental and health damages. She said that "the people have been experiencing regular inflow of sea water, which pollutes rivers and streams that are the major sources of water for drinking and cooking". She also stated that long-standing pollution attributed to pipeline leaks, hydrocarbon waste dumping and oil spills, all have negative effects on people's health (Figure 5.58). The majority of people in the communities "complain of stomach-ache and skin irritation" according to the nurse. Moreover, "waterborne illnesses like cholera, typhoid and diarrhoeal diseases from unsafe drinking water present challenges for local communities", as in Table 5.18..

Table 5.18. Key responses from the respondents: Results from interviews of Health professionals

Location	Major environmental health issue	How can you best explain the cause of the illness from oil production?	Do people report to your clinic or find other medical means?	What can be done?
Tsekelewu	Oil pollution and salty water from artificial canals, constructed by Chevron oil company.	Health problems which resulted from drinking brackish and contaminated water from flooding of sea water into freshwater. Illnesses like cholera, typhoid and diarrhoeal diseases from unsafe drinking.	Some local people used to come, while some do find alternative medicines like traditional medicines.	Government should improve health care services.
Eket	Oil pollution and contamination of drinking water from oil production activities of multinational oil companies.	Pollution: Drinking water from oil production resulted into skin swelling.	Not all affected people come to the clinic but they seek traditional medicines or spiritual healing.	Health services in the entire Niger Delta need reforms, for better health care of oil- production affected people.
Oboolo	Oil pollution and contamination of drinking water from oil production activities of multinational oil companies.	Pollution from oil production, oil contamination of rivers and streams, which are major sources of drinking water.	Many people in the community still believe that skin swelling can only be healed by traditional medicines or spiritual healing.	Pipe water projects must be developed and implemented in the communities where oil pollution has been causing ill-health.

The health professionals also in Eket said that the major health problems from oil activities include itchy skin, abdominal pain, diarrhoea, skin irritation and skin swelling (Table 5.18). During our visits to Eket and Oboolo villages, oil production impacts were observed, these ranged from water contamination by oil, to death of vegetation which could not tolerate environmental pollution from oil activities. Interestingly, a local nurse in Oboolo community also added that many people in the community "still believed that skin swelling can only be healed by traditional medicines or spiritual healing". They believe that this disease affects those who sin against the gods of their community. An important finding from the entire health professional interviews undertaken was that gas flared from nearby oil plants, have caused an epidemic of bronchitis in adults, as well as asthma and blurred vision in children living in the communities where there are oil fields.

The health professionals therefore said that they believed the majority of illnesses in the communities are related to the "products of the gas flares, including bronchial, chest, rheumatic, and eye problems in children". The majority of local people in "the communities are poor, and therefore affordability of good health-care, together with low-quality public health services in the Niger Delta are problematic" said the nurse in Oboolo. Perhaps, these results broaden our understanding of both health and societal implications of environmental changes on the Niger Delta, as noted from remote sensing findings, and also that different communities have different problems.

Figure 5.56. The health professionals pictured during field work in Tsekelewu. One of the field assistants (to the right) is interviewing the health professionals.

Figure 5.57. Photograph of health professionals taken by the researcher during field work in Tsekelewu. To the right: one of the local persons hired to help during the field work in Tsekelewu

Figure 5.58. One of the field assistants (to the right) following an interview with a nurse (to the left)

5.3.2. Quantitative Assessment of Questionnaires

The results of questionnaires are presented in this section, based on the perceptions and awareness of local people and the environmental and health professionals. As discussed in chapter four, the main aim of the questionnaire is to validate the findings from remote sensing methods. In this section, the findings from the questionnaires are discussed under two main subheadings: Societal implications of landuse change; and Health impacts of oil production on the Niger Delta.

5.3.2.1. Perceptions of local people on landuse change

Table 5.19 shows the perception of local people on landuse change and and on the drivers of this change in the Niger Delta. It is clear from Table 5.19 that changes in landuse have diverse meanings for different people in the Niger Delta, perhaps based on their perceptions of their physical environments, the type of landuse and degrees of changes in the landuse. The results show that the majority of respondents in Okomu, Tsekelewu, Eket and Oboolo perceived that urban areas (95.54%, 87.34%, 93.12% and 88.54% respectively) and farmland (91.87%; 80.01%; 85.71% and 87.53% respectively) expanded, while forest decreased (98.40%; 87.70%; 86.70% and 90.26% respectively) over the last twenty-five years (Table 5.19). From Table 5.20, it is obvious that there are different views on the drivers of the major landuse changes in the Delta and different communities have different views on the causes of changes in their environments. The majority of people at Okomu, Tsekelewu, Eket and Oboolo perceived increase in population as the major driver of urban and farmland expansion. For example, about 64.62%; 64.25%; 61.98% and 59.34% in respective locations perceived that the increase in urban population is the major cause of urban expansion, while about 78.39%; 67.81%; 64.98% and 68.78% respectively perceived the factor (increase in population) to be responsible for farmland expansion (Table 5.20).

On the other hand, there appears to be different opinions as to the drivers of deforestation in different locations, and there is far less agreement in general with the percentage counts being much lower. In Okomu for instance, the majority of the people perceived that road network (45.92%) and illegal logging (30.73%) are the main causes deforestation (Table 5.20), but in Tsekelewu, Eket and Oboolo, the majority of people (39.23%; 46.93% and 45.92% respectively) considered oil production activities to be the main driver of deforestation in their communities. The reasons for the variation in their views might be because different environmental problems affect different locations in the Delta. The key information that can be deduced from these results is that all the people perceived that illegal logging, increase in population, increased road network, expansion of urban and farmland are the major causes of decline in forest in the study area.

Table 5.19. Perception of people on landuse change in the Niger Delta

Perception	Changes	Okomu (%)	Tsekelewu (%)	Eket (%)	Oboolo (%)
Urban	Expanding	95.54	87.34	93.12	88.54
	Declining	2.54	1.15	2.11	6.54
	No change	0.11	4.01	3.05	2.1
	Do not Know	1.81	7.5	1.72	2.82
	Total	**100**	**100**	**100**	**100**
Farmland	Expanding	91.87	80.01	85.71	87.53
	Declining	1.01	10.01	7.14	6.12
	No change	3.11	5.96	2.05	3.01
	Do not Know	4.01	4.02	5.1	3.34
	Total	**100**	**100**	**100**	**100**
Forest	Expanding	1.53	5.1	5.1	2.35
	Declining	98.4	87.7	86.7	90.26
	No change	1.45	2.15	7.15	3.35
	Do not Know	1.04	5.05	1.05	4.04
	Total	**100**	**100**	**100**	**100**

Table 5.20. Perception of people on the drivers of landuse change in the Niger Delta

Perception	Drivers	Okomu (%)	Tsekelewu (%)	Eket (%)	Oboolo (%)
Urban expansion	Increase in Population	64.62	64.25	61.58	59.34
	Road network	14.26	1.91	1.41	1.91
	Oil Production	10.11	26.34	29.34	30.25
	Do not Know	11.01	7.5	7.5	8.5
	Total	**100**	**100**	**100**	**100**
Farmland expansion	Increase in Population	78.39	67.81	64.98	68.78
	Road network	14.08	26.45	25.99	16.44
	Oil Production	5.32	3.53	3.02	3.53
	Do not Know	2.21	2.21	6.01	11.25
	Total	**100**	**100**	**100**	**100**
Deforestation	Increase in Population	10.34	11.01	10.31	10.01
	Illegal logging	30.73	20.37	20.01	15.69
	Road network	45.92	10.95	14.64	15.01
	Oil production	0.93	39.23	46.93	45.91
	Farmland expansion	10.04	12.12	8.04	10.04
	Urban expansion	2.00	1.21	0.04	2.30
	Do not Know	0.04	5.12	0.04	1.04
	Total	**100**	**100**	**100**	**100**

5.3.2.2. Health Effects of Environmental Changes in the Niger Delta

The variations in peoples' perceptions of health effects resulting from environmental changes and oil production in the different locations of the Niger Delta, over the past thirty years are shown in Table 5.21 and figure 5.59 shows the results from the questionnaire surveys, which appear to vary from one region of the Delta to the other. In Tsekelwu for example, many participants said that skin irritation (42.6%) and stomach-ache (23.4%) are the major health effects resulting from environmental changes in the region. However, the majority of people in Eket (51.1%) and Oboolo (54.1%) perceived that stomach ache is the major effect of oil production in the region (Table 5.21). Similarly, the results show that respiratory problems are the major health effects of environmental changes in Eket (34.4%) and Oboolo (24.6%).

Table 5.21. Variations in peoples' perceptions of health effects resulting from environmental changes and oil production in the different locations of the Niger Delta, over the past thirty years

Health cases	Tsekelwu (%)	Eket (%)	Oboolo (%)
Dry throat	9.5	1.5	8.2
Skin irritation	42.6	4.5	3.2
Stomach-ache	23.4	51.1	54.1
Diarrhoea infections	5.7	2.1	5.4
Scratchy throat	13.3	6.4	4.6
Respiratory problems	5.5	34.4	24.6
Total	100	100	100

Variations in results obtained from these locations are likely to be due to the fact that different environmental problems prevail in each location. As it has been reported in the literature (Chapter two), and also shown in Table 5.18, different types of environmental changes occurred in different regions of the Delta. The results of remote sensing show that environmental change in Tsekelwu is basically due to inflow of saltwater from contractions of artificial canals, while remote sensing has little to say about Eket and Oboolo. But, they appear to be due to the direct impacts of oil pollution (Figure 5.60), such as oil in water and soot in the air from flaring. Thus, the high values of skin irritation (42.6%) and stomach-ache

(23.4%) in Tsekelwu might be as a result of contamination of major source of water by inflow of saltwater. What is clear from these findings is that social research aids in validating the results of oil pollution studies from remote sensing analysis at Tsekelwu, but not at the other locations, as remote sensing analysis is not good at detecting most of the oil related problems.

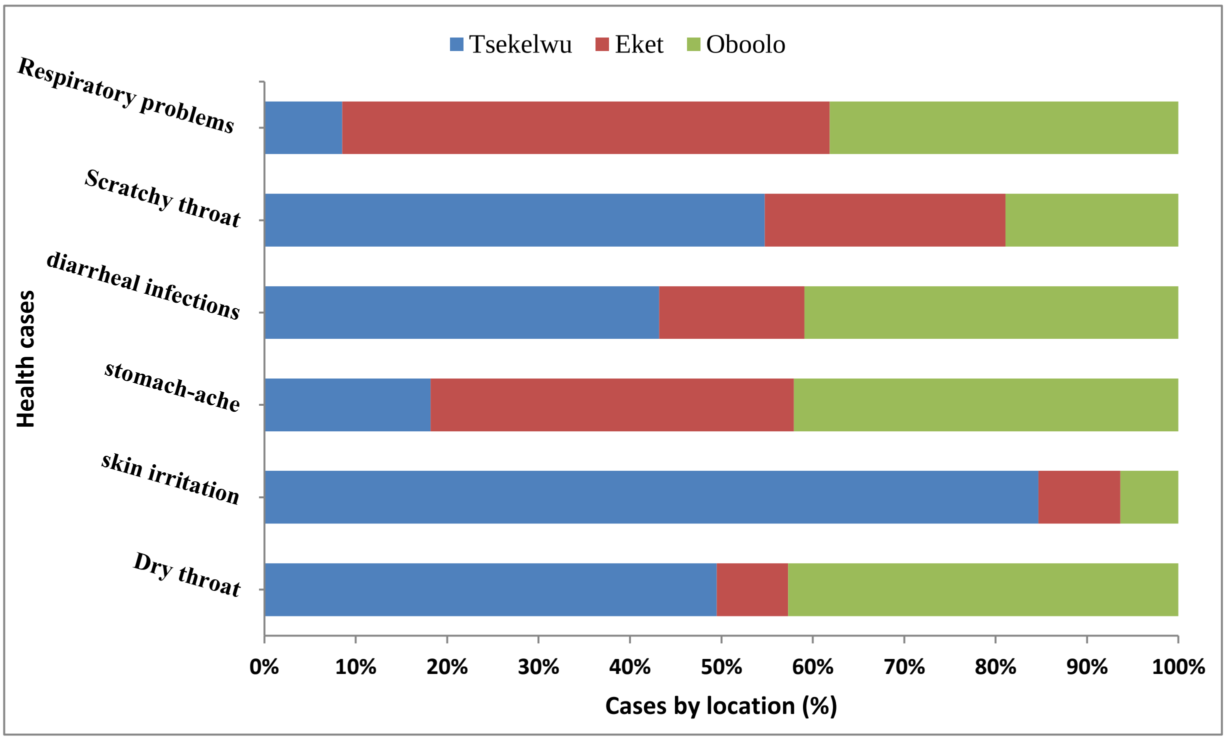


Figure 5.59. Variations in peoples' perception of health effects resulting from environmental changes and oil production in the different locations of the Niger Delta

Figure 5.60. Some vegetations have died in the Niger Delta, apparently resulting from frequent oil pollutions in the region (Photo from UNEP 2007)

CHAPTER SIX
DISCUSSION

6.1. Spatiotemporal Change in Landuse in the Entire Niger Delta

6.1.1. Deforestation

The remote sensing results presented in chapter five illustrate two major findings in terms of deforestation. Firstly, that the Niger Delta of Nigeria has experienced tremendous change in landuse over the past three decades. Secondly, that the patterns and intensity of changes in deforestation vary by different forest types in the Delta.

On the whole, the results of the landuse change analysis suggest that urban areas are expanding and consuming farmland. With more demand for farmland; the high rural population; and its rapid growth, have all resulted in expansion of farmland, which has led to deforestation and degradation of the forest resources in the region. The deforestation process appears to be slowing down in many areas, however, rates are still high and those forests that are still intact are being degraded. These results agree with previous studies that have discussed general changes in the environment of the Niger Delta (Ologunorisa 2001; Obire and Amusan 2003; Jike 2004; Uyigue and Agho 2007; Ibaba 2010; Onojeghuo and Blackburn 2011). They concluded that drivers of landuse change were principally from rapid urbanization, agricultural expansion, deforestation and degradation of mangrove, especially from petroleum activities. For instance, Uyigue and Agho (2007) and Onojeghuo and Blackburn (2011) examined landuse changes in the region and showed the almost complete absence of primary forests. They also suggested that there are patches of primary forest remaining, particularly at the centre and South-western part of the zone; mostly around Gilli-Gilli forest reserve. It is also shown from the results of this study that the rate of environmental change varies both spatially and temporally. For example, deforestation is high in the lowland rainforest, but much lower in freshwater swamp and mangrove forest, because the land is not good for agriculture; being covered in swamps and subjected to seasonal flooding, both of which limit accessibility. Though, only a small part of the freshwater swamp forest has been lost, because they are not immune to human interferences, as the NDVI results have shown a high degradation rate.

The main reason for forest degradation reported in the literature is illegal selective logging. Studies by Oates (1995), Ite (2001) and Adekunbi (2011) have reported that the freshwater swamp forest in the Delta is being selectively logged and the logs floated out down the rivers and then up the coast to cities, which may well explain the forest degradation observed in chapter five. Other studies by Omokhua and Koyejo (2008); and Mmom and Arokoyu (2010) have reported similar scenarios. They identified selective forest harvest as a traditional forestry practice in the Niger Delta, whereby forest is utilized as a source of fuel wood, building materials, fish traps, boat carving, fishing platforms as well as shoreline protection. Thus, it is likely that the forest in the Delta has never known effective protection.

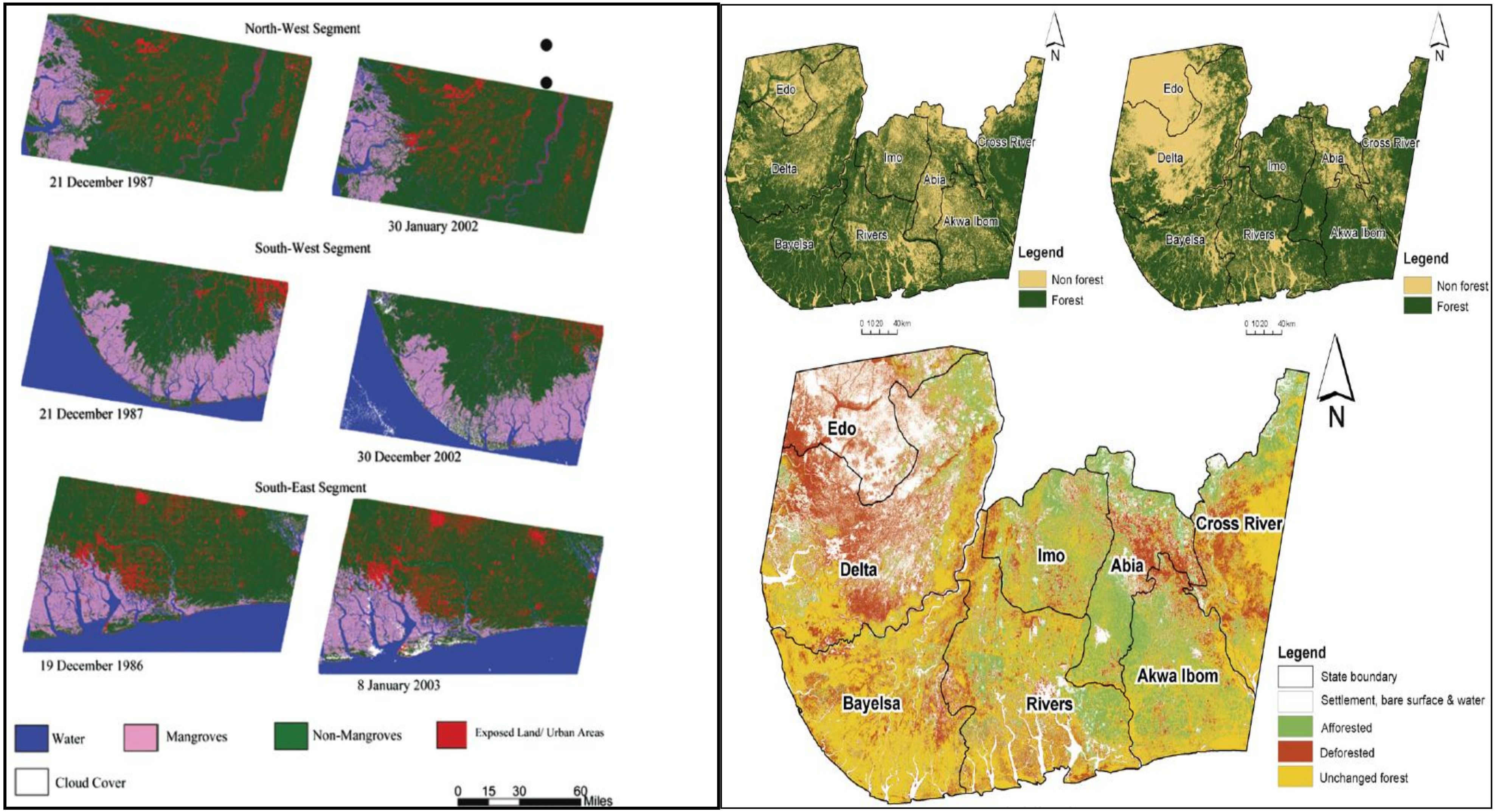
A number of recent studies have reported also that deforestation in the Niger Delta has increased over the past few decades (Godstime et *al.* 2007; Hellermann 2007; Omokhua and Koyejo 2008; Mmom and Arokoyu 2010; Onojeghuo and Blackburn 2011). Despite this fact, little has been done in terms of assessing the rate of change in different forest types in the entire Delta. Instead, studies have focused on a diverse array of environmental degradation issues such as implications for wildlife (Blench 2007; Godstime *et al*. 2007); impacts of oil spillage on vegetation (Amnest 2009; Atakpo and Ayolabi 2009; Eregha and Irughe 2009); conflicts and politics (Babatunde 2010); and human rights violations (Aaron 2006; Ebeku 2006; Ibaba 2010; Okon, 2012). A few studies have however, looked at large scale landuse change. It is clear that there has been a steady degradation and loss of biodiversity in the mangrove forests of the region (Godstime *et.al*. 2007; Salami *et.al*. 2010; and Mmom and Arokoyu 2010). Godstime *et. al.* (2007) and Onojeghuo and Blackburn (2011) have looked at landuse change for all forests in the majority of the Delta, without discriminating between forest types like this study does. The results of the present study are inline with these studies, showing the forest of the Niger Delta has been significantly altered.

The findings of these latter two studies, and the results of the present study, were based on satellite data analysis, but used slightly different change detection methods over different time periods for different areas. Onojeghuo and Blackburn (2011) applied unsupervised classification methods, to monitor forest transition in the Niger Delta, using satellite data from 1986 to 2007. Their study analysed the rate of deforestation in the Niger Delta using political states, though Ondo State was not included in their study (Figure 6.1B). On the other hand, Godstime *et al*. (2007) examined and estimated changes in the spatial extent of the mangrove forest, using Landsat imagery between 1980 and 2003. Table 6.1 compares these different deforestation rates to the ones found in this study. The deforestation values obtained for mangrove in the present study are much higher than that of Godstime *et al*. (2007). The reason for this might be due to the disparities in the years of the datasets used (Table 6.1), and the different spatial of the two studies (Figure 6.1). Moreover, the present study covers all mangroves in the Delta for nearly three decades, and uses an up to date dataset. However, Godstime *et al*. (2007) covers just twenty-one (21) years (Table 6.1), and does not consider Ondo State and the Southern part of Cross River State (Figure 6.1A). Thus, these mangrove deforestation results cannot really be compared, and the results from this thesis should be considered the most reliable figures. Onojeghuo and Blackburn (2011) did not split the Delta ecology into its different forest types, as was done in this study. Thus to compare our results to theirs, we can merge all forest types. If we do this, we get a similar but slightly lower deforestation rate, even though this PhD covers a larger area and a longer period of time. Given that, Onojeghuo and Blackburn (2011) reported an accuracy of about 90%, as this study does, then both estimates of total forest cover are just with the margins of the reported error, and thus can be considered roughly equivalent.

Table 6.1. Variations in deforestation rates obtained in the present study compared with the previous studies

	Lowland rainforest (km^2**)**	**Fresh water swamp (**km^2**)**	**Mangrove (**km^2**)**	**Years of dataset used**
Godstime *et al*. (2007)	NS	NS	213	1987-2002
Onojeghuo and Blackburn (2011)	Combined: 13812			1985-2003
Present PhD study	8324	1424	1535	1984-2011
	Combined: 11283			

NS = Not Studied



A: Area covered by Godstime et al. (2007)

B: Area covered by Onojeghuo and Blackburn (2011)

Figure 6.1. Area of forest determined by previous studies in the Niger Delta

Results from the landuse change analysis suggested that urban expansion is a driver of both farmland expansion and deforestation, but not in all types of forest. There is high rate of urban expansion in lowland rainforest, compared to other ecological zones in the Delta. The high rate of urban settlements in the rainforest clearly contrasts to other forest types and might be due to the fact that the rainforest region is good for construction of buildings, being the driest part of the Delta, with no creeks and no seasonal flooding (Ebeku 2006).

The rapid increase in urban area in the Niger Delta could be attributed to a number of factors, principal among these are: 1) a high population with a rapid population growth 2) a high migration rate of people from other parts of Nigeria, who were searching for employment in the oil industry and 3) a high rural-urban migration. A report by NDRDMP (2006) has also shown that the rate of rural-urban migration is about 5.3% per annum in the Niger Delta. The main reason for this is a lack of land for an expanding population and poverty in the rural settlements, with the majority of people in rural areas living below the poverty line. Consequently, many people are being pushed out of the rural areas into the urban areas in search of an improved life. This migration might contribute to the considerable expansion in urban centres in the Delta observed from the results of the present study, though the high population growth may also have contributed to this.

Several studies have reported that expansion in urban areas might be attributed to the general increase in population of the Niger Delta over the past three decades. The Niger Delta is known for being the region with the highest population density in the West Africa (NDDC 2004, NDRDMP 2006). Studies by NDDC (2001; 2004)and AAS, Population Census Statistics(1999 and 2006) reviewed in chapter two, have revealed that the population has increased by about 25% from 1991 to 2006. A population projection reported by NDRDMP (2006) suggests an increase of about 4.4% per year, equivalent to an addition of between 11 and 18 million people (Figure 6.2) for years 2005 to 2020. The NPC (2006) also estimated the population density of the Niger Delta to be about 265 people/km^2 and showed that the highest population densities are found in the South-eastern part of the Delta (Figure 6.3), the location of high urban expansion in the remote sensing classification results (as in chapter 5). Thus, as would be expected, larger urban settlements are located mainly in areas of high population density.

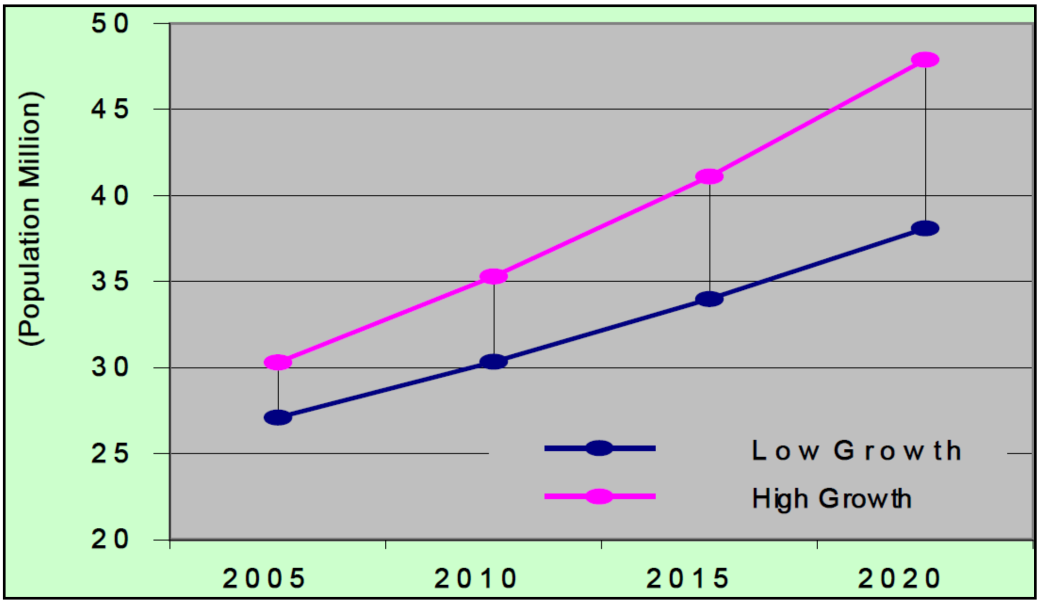


Figure 6.2. Population projection for the Niger Delta (Source: NDRDMP 2006)

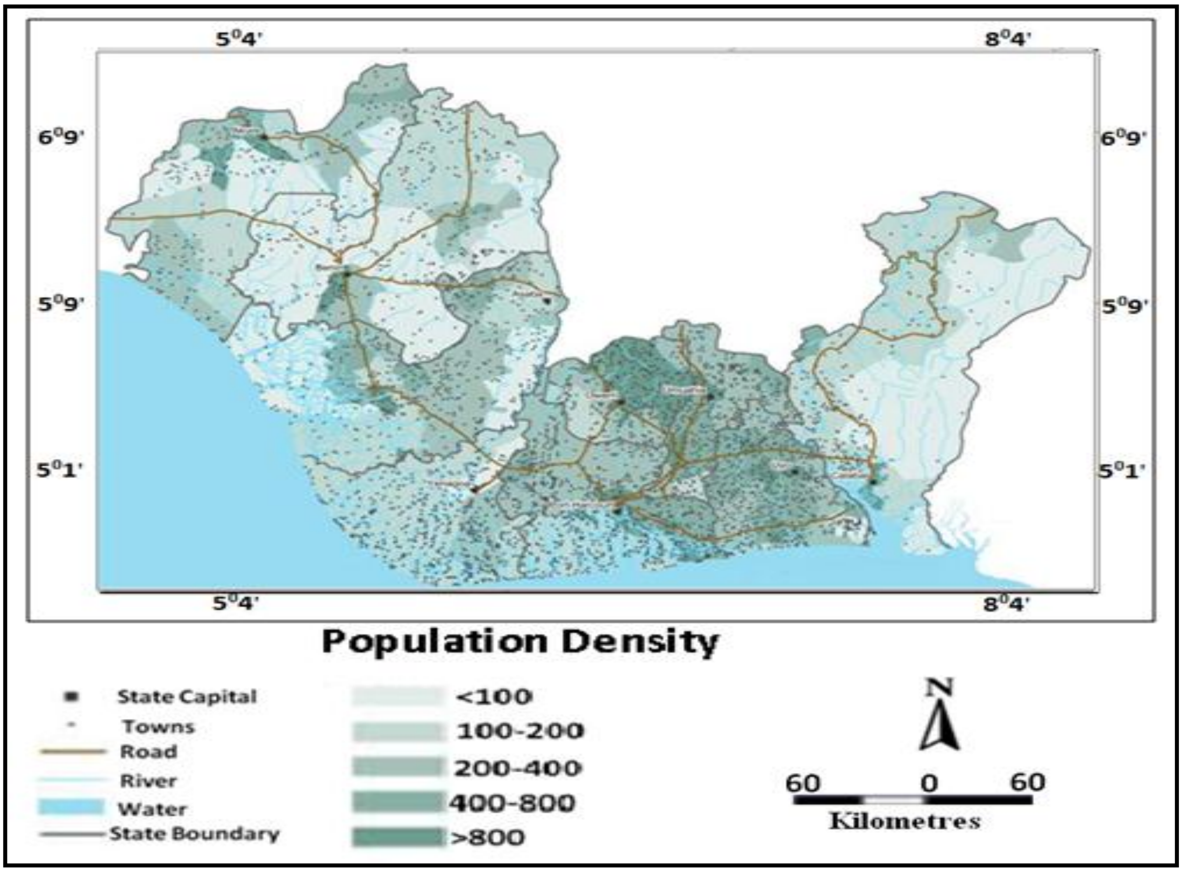


Figure 6.3. Population density and sentiments in the Niger Delta in 2006 (Data source: NPC between 1991 and 2006 and NDRDMP 2006)

However, the present study does not show emphatically here that population growth is the main driver of urban expansion. It is found in chapter five (from correlation results) that factors controlling landuse change are complex, and population cannot be regarded as the only factor. Furthermore, it has been reported in the literature that urban expansion is affected by several factors that have not been considered in this study, which includes social, cultural and economic factors/drivers (Geist and Lambin 2001, Lambin *et. al*. 2001, Le-Le and Yi-Ming 2010). It is probable that these drivers are playing an important role in the Delta, and studying these issues would provide a fruitful area of further research.

6.1.2. Farmland expansion

It is evident from chapter two and results presented in chapter five that agriculture is a major component of landuse in the Niger Delta. Expansion of farmland into forests leads to deforestation, as discussed in Section 5.1.13. Earlier studies have shown that over 65% of the population of the Niger Delta of Nigeria engage in farming (Alagoa *et al.* 1988, Iyayi 2004, Jike 2004, Aaron 2006). Moreover, previous studies (Ebeku 2006; NDRDMP 2006; Godstime *et al* 2007; Hellermann 2007) have noted that there are few existing records about the extent of deforestation in the lowland rainforest. Though, NDRDMP (2006) reported that the Niger Delta has been largely cleared for agriculture and the remaining vegetation are now mosaic of forest, farmland, oil palm and rubber plantations. The present study has demonstrated that lowland rainforest is now largely deforested, mostly due to agricultural practices, though the other forest types grow on land that is not good for agriculture, so their soil have largely been spared. It is tempting to attribute this to increasing demand for land by the rapidly growing population, especially in the lowland rainforest, where land is under intense pressure from expanding farmland and urban settlements. However, the correlation analysis shows that this is a simplistic view and other factors have an important role to play (as discussed below).

6.1.3. Landuse change Implications on wildlife

All forest types are suffering from either rapid deforestation, degradation or both and this is occurring in both protected and unprotected areas. The wider literature suggests that the animals in many reserves are threatened, and some might already be extinct. For example, the Niger Delta pygmy hippopotamus mainly located along the boundary between lowland rainforest and freshwater swamp forest of the Niger Delta (Blench 2007; UNEP-WCMC 2007; Were, 2009). Two major forest reserves where Pygmy Hippos has been reported in the past are Egbedi Creek and Upper Orashi Forest Reserve (UNEP-WCMC 2007, Blench 2007). The major concern of these studies has been the regular disturbance resulting from degradation in the reserves. The main threat to the survival of Pygmy Hippo species, according to Blench (2007), appears to be their habitat disturbance from logging, especially in the Upper Orashi Forest Reserve. Our results confirm those of UNEP-WCMC (2007), Blench (2007) and Were (2009) that Upper Orashi Forest Reserve suffers little deforestation, but there appears to be increase in degradation, perhaps due to logging, as discussed in Section 5.1, andthis does not work well for the survival of these species in Nigeria.

Findings of interviews with a member of Nigeria Conservation Foundation (NCF), the Director of the Institute of Ecology at Obafemi Awolowo University, Ile-ife Nigeria, the Manager/Staff of Okomu Forest Reserve and other local people who live in the reserve indicate that deforestation and degradation impacts are very significant on wildlife. All the interviewees believed that reduction in number and extinction of some wildlife in forest reserves in the Niger Delta could be attributed to the intensive hunting, forest clearance and logging in protected areas. These people mentioned Sclater's guenon, White-throated guenon, Red colobus monkey, Chimpanzee and Niger Delta pigmy hippopotamus as the most endangered animals in the Delta. Numerous studies have shown that the major problem confronting wildlife conservation in the Niger Delta is the increasing rate of habitat loss resulting from human activities (Blench 2007; Phil-Eze and Okoro 2008; Were 2009). Though, the results from remote sensing show that freshwater swamp forest has less human impact compared with lowland rainforest, this might be because swamps do not permit readily human accessibility and make poor farmland. Previous studies have shown that freshwater swamp forest, through its species diversity, plays a pivotal role at the local and national levels, by shaping the environment and influencing local people (NDDC 2001; Blench 2007; Mmom and Arokoyu 2010). Therefore, there is urgent need for proper implementation of freshwater swamp ecosystem conservation. It is also suggested by environmentalists interviewed in this study that forest policies need to be reformed to prevent deforestation, as well as implementing large-scale rehabilitation of degraded lowland rainforest as best options for halting forest decline.

There is a considerable literature to back up the results of extreme deforestation and degradation in parks, and the fact that this is having large detrimental effects on animal populations. Studies by Morakinyo and Tooze (2007), Greengrass 2009 and Bown *et al* (2011) estimated that the remaining forests in many reserves have been degraded, affecting biodiversity such as Chimpanzee; Monkeys; Antelopes; Pygmy hippopotamus; Spotted genet; Black squirrel; Elephant; Leopard and Black pig. Thus, the majority of the endangered animals are now restricted to few forest reserves, where they experience little disturbances. Other studies by Hilton-Taylor (2000); and Baker and Olubode (2007) reported that Chimpanzee are found predominantly in protected areas along Western part of the Delta while Red colobus monkey and Sclater's monkeys are found in forest reserves in freshwater swamp forest. Though these reserves have low deforestation rates, species are also threatened due to gradual increase in degradation of their habitats.

6.2. Linking social results with findings from remote sensing

The results from social research supported the main findings from remote sensing research that the environment of the Niger Delta has been severely impacted by various human activities. In this section, the inference of the findings from social research and remote sensing are discussed under two main subheadings: Societal implication of landuse change and Impacts of oil production and other environmental changes on the Niger Delta.

6.2.1. Societal Implications of Landuse Change

The results from questionnaires, interviews and focus group discussions show that during the past three decades, environmental degradation resulting in change in landuse and forest degradation, as noted from remote sensing; and environmental pollution from oil production; has contributed a significant environmental problem confronting the Niger Delta of Nigeria. These environmental problems have led to losses of arable land, lives and properties. On the other hand, what is evident from the results of both remote sensing and social research is that the people of the Niger Delta are highly dependent on this decaying environment for their livelihood. Local inhabitants traditionally make their living as farmers, fishermen and hunters through exploitation of the resources from land, water and forest and these have been affected by changes in the environment of the Delta.

Overall results from social research therefore provide an explanation of the major drivers of landuse change as revealed in remote sensing, especially deforestation in the forest reserves in the Delta for purposes of agriculture such as in Okomu. Urban expansion and the socio-economic development of infrastructure cause environmental problems in most lowland rainforest zone of the Delta. The majority of forest staff and environmentalists interviewed blamed illegal logging, firewood collection by local people and illegal farming activities within the forest reserves as the main drivers of deforestation. Farmers and local people themselves, of course, have a somewhat different perspective. Although, farmers readily admit that they do not plant trees any more (replanting of trees is one of the objectives of the Taungya system) because illegal loggers usually bribe forest staff, to take permission to cut the trees. Though, we could not validate this claim. Thus, this study indicates that corruption, accessibility created by road networks, uncontrolled removal of trees by the armed loggers, together with laxity and greed of forestry staff are major causes of rapid deforestation in the Delta.

6.2.2. Implications of Oil Production and Environmental Change in the Niger Delta

The results in chapter five show that remote sensing can only play a limited role in understanding oil pollution in the Delta. It is not effective for mapping oil spills, but it can be used to study the effects of the development of certain types of oil infrastructure. However, the results obtained from social research imply that the health impact of oil production and other environmental change in the Niger Delta is a critical issue. From the results of questionnaires, interview and focus group discussions, it is obvious that health effects of environmental degradation are important, but are not seen as problems by most government officials. Despite the fact that local people perceive that the responses of local government to environmental change around them is sometimes good, it appears that they believe that federal government is unconcerned. The reasons for this might be because political instability in the country and economic issues take center stage in national subject matter nowadays, while health and environmental issues receive little attention. What complicates the situation is the lack of accurate health data which precludes appropriate decision making and planning. However, the results from social research (and in case studies of remote sensing) have shown that the environment and health of the people were affected by environmental degradation resulting from activities of multinational oil companies in the region.

Earlier studies have previously reported that activities of the oil industries constitute serious environmental health hazards to the people in Delta region (NDRDMP 2006; UNDP 2006; Babatunde 2010; Omorovie 2012; Iwegbue *et.al.* 2012). Likewise, a report of the Niger Delta Regional Development Master-plan [NDRDMP] in 2006 stated that “water-related diseases are one of the most critical health problems in the Niger Delta, and the health issue most closely linked with environmental degradation”. UNDP (2006) further noted that this environmental disaster has a tremendous impact on both human health and ecosystems in the region.

One important environmental problem noticeable from focused groups, questionnaires and interviews is gas flaring. The results from social survey showed that about 79% of people perceived that sore throat is one of the health illnesses resulting from gas flaring, while about 88% of people also agreed that gas flaring causes respiratory problems. Several studies have been conducted to examine the impacts of gas flaring on the Niger Delta. Until recently, Nigeria flared about 75% of the gas she produces, flaring more gas than any other oil producing countries in the world (UNDP 2006). Awosika (1995) also reported that over 102.3 Million cubic meters (81.7% of the gas produced) was flared in early 1980s. Likewise, CADA (1997) noted similar figures, stating that out of approximately 1000 standard cubic feet (scf) of gas produced in Niger Delta with every barrel of oil, 80% was flared.

Furthermore, a study by Egbuna (1987) noted that the total gas flared in 1986 from over thirty oil and gas fields in Nigeria yielded about 60 x $l0^9$ KWh, which approximately equals to annual energy supplied by Power Holding Company of Nigeria. Moreover, Aaron (2006) also stated that there were about 123 flaring sites, which flare over 1.8 billion cubic feet of gas every day in the Niger Delta. These figures illustrate that a large proportion of the associated gas produced with crude oil was flared. This problem is as a result of lack of adequate infrastructures to make use of the gas as alternative energy in Nigeria. In recent years, there has been a small decline in gas flaring by oil and gas companies operating in the region, largely because of a gas flaring penalty introduced by the government. Oil companies have started to address the problem by capturing the gas for liquefaction and export; however, it is clear that health effects remain, and much more needs to be done.

Despite reduction in gas flaring in the Delta, the social survey on human health revealed that some communities suffered respiratory problems associated with gas flaring. Other studies also supported this view. Leahey *et al* (2001) and Ishisone (2004) reported that gas flaring has potentially dangerous effects on the health and livelihood of the communities around the flaring site, because gas flaring releases poisonous chemicals which are dangerous to human health. A study carried out in ten gas flaring locations around the Niger Delta by Sonibare and Akeredolu (2004) measured the composition of natural gas and found very high methane levels. They also showed that human exposure to such substances can lead to a variety of respiratory problems such as breathing difficulties, lung cancer and aggravate asthma. Though little scientific investigation has been conducted, several hospital records have shown cases of breathing difficulties and pain amongst many children in the Niger Delta (Ologunorisa 2001).

It is astounding to note that many of gas flaring sites in the Niger Delta are located very close to local communities. Most of these communities lack adequate fencing or protection against the dangerous risk from the heat of the flare. Human health however, is not the only problems that have been reported. Osuji and Onojake (2004a; b) showed that gas flaring has contributed to the increase in atmospheric temperatures in recent times. In the area that is directly surrounding the flare, no vegetation can grow as a result of the heat it generates. A recent study by Dung *et al* (2008) and Orimogunje *et al* (2010) have also shown that air and soil pollution, together with retardation in vegetation development, is evident close to the gas flaring point. The results of this study also show that crop yields are higher at locations farther away from the gas flare sites. They all concluded that high atmospheric temperatures around the gas flare site, are the most likely cause of the reduction in crop yields.

Like earlier studies, this study has shown that problems associated with canal construction by oil multinational companies in the Niger Delta include destruction of mangroves and freshwater forests and farm crops (Fagbami *et al.* 1988; Abam 2001; Enemugwem 2009). The social survey has however shown for the first time, that there are health effects associated with canals construction including diarrheal infections, skin irritation and stomach-ache, resulting from drinking brackish waters sometimes polluted by oil.

6.3. What are the Drivers of Landuse Change in the Delta?

The correlation results show that the drivers of landuse change in the Niger Delta of Nigeria are complex. Previous studies have reported that the increase in population leads to expansion of farmland and urbanization, and these are the major factors driving deforestation. The majority of these studies are based on speculation without empirical analysis of these drivers. For example, the study by Eregha and Irughe (2009) noted that as population increases in the Niger Delta, urban areas also expand, consuming farmland, and this has resulted in deforestation in the Delta. It is clear from the present study that these factors are not the only ones that contribute to deforestation. The low correlation between urban expansion and deforestation suggests it is not the main cause. However, the high negative correlation with distance to major road suggests that the decline in forest in the Niger Delta is more closely related to accessibility. This study finds that this is a key driver of deforestation in the Delta.

The conceptual model developed in chapter three (Figure 6.4) also suggests that there are multiple drivers of landuse change. From these other studies (e.g. Geist and Lambin 2002; Patarasuk and Binford 2012), and the findings of this study, we can develop a list of possible drivers of deforestation in the Niger Delta (Figure 6.2), due to the political, social, economic, cultural, political, and the biophysical nature of the region. The details associated with the majority of these factors, are not researchable within the limited period of this study. But, the lists presented here, which include those also suggested in the wider literature, present the drivers, as in Table 6.2, that probably have a role to play in the deforestation of the Niger Delta.

Table 6.2 Possible drivers of landuse change in the Niger Delta

Possible drivers of landuse	List of variables
Proximate	Extension of infrastructure such as road, the network and canals. Wood extraction both commercial and fuel wood collection.
	Agricultural expansion both subsistence and plantation agriculture.
Underlying	Lack of political will. Ineffective forest management, corruption in both local and federal government. Social and demographic factors such as rural-urban migration and the high population and its rapid increase, urbanization and industrialisation. Cultural factors such as the unconcerned attitude of people living in the Delta.
Biophysical	The topographic nature of the region such as mangrove and freshwater swamp forest where the nature of the soil and its poor drainage restricts development.

The dynamic driving forces which influence the rate of landuse in the Niger Delta are human activities such as urbanisation, industrialisation, communal and commercial deforestation. All these are enhanced by a high population and its rapid increase; accessibility to forest reserves through the expansion of transportation networks; and other infrastructure developed by the government and from oil production in the Delta. Corruption, lack of political will and unenforced environmental laws are other major drivers, though these are not easily understood because of lack of accurate data about them. These findings accord with the conceptual model developed in chapter three (Figure 6.4), which are influenced by the impacts of economy that have the potential to significantly affect the sustainability of the Delta environment. Although, the global and local economy are often involved in deforestation processes in other parts of the world (Lambin *et al.* 2001; Geist and Lambin 2002), the global economy has not played a larger role in the Niger Delta, apart from the influence of the oil industry at all levels of the society. This is evident by the fact that most of the wood logged in the Delta is used for consumption within the country, and not for export.

The findings from this study, though not agreeing with many of the previous studies conducted in the Delta; do correspond with previous studies on the drivers of landuse change in other parts of the world. Foremost of these studies are the works of Lambin *et al* (2001); Geist and Lambin (2001); Lambin *et al* (2003); Estes *et al* (2012); and Patarasuk and Binford (2012). For example, Geist and Lambin (2001) examined what drives deforestation in the tropics. The underlying causes they found out included accessibility of people to the forest, as is also found out in the Delta. Also, Patarasuk and Binford (2012) noted the same factors as Lambin *et al* (2003) that the road network development is a curtail factor of deforestation in the Lop Buri province of Thailand.

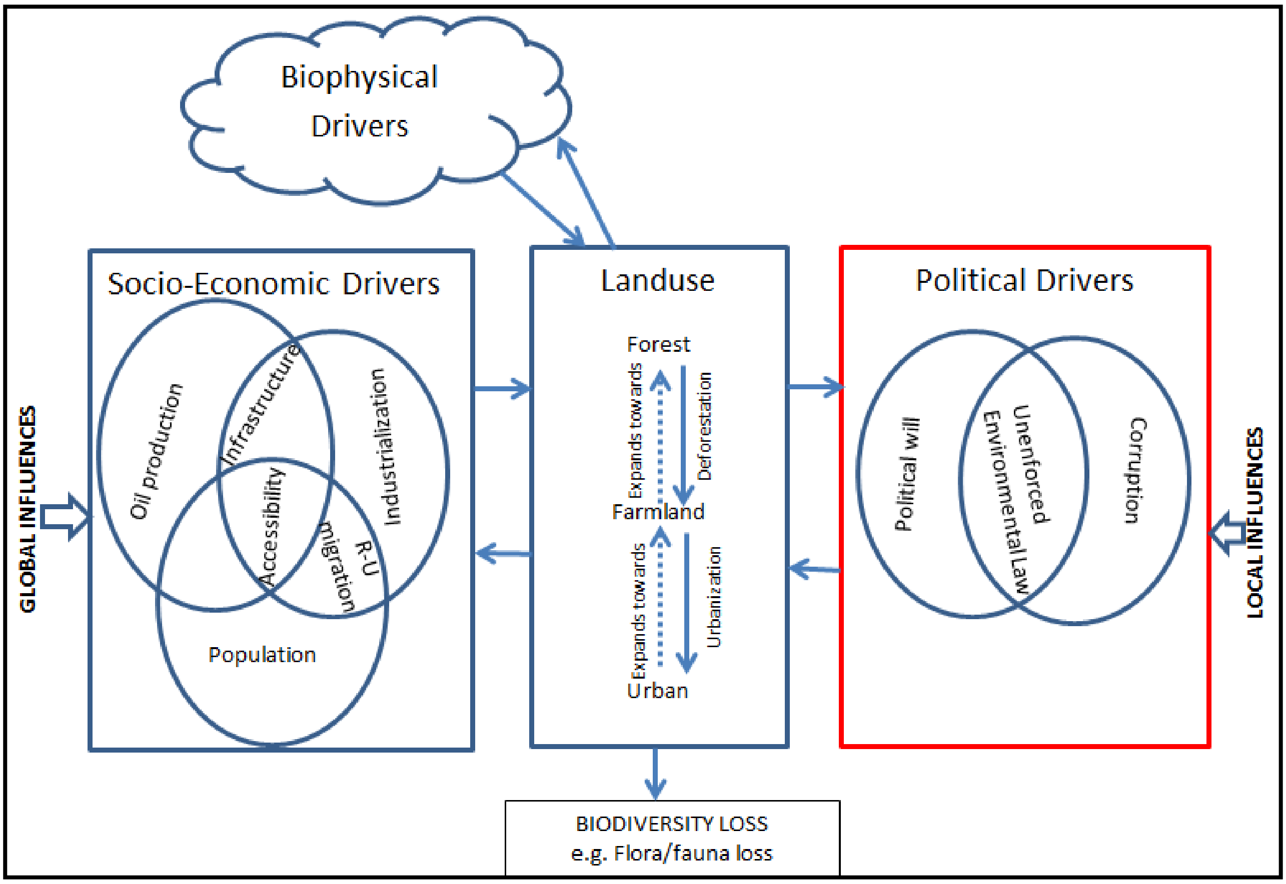


Figure 6.4. Dynamic-driving forces conceptual model of the drivers of landuse change. R-U migration means Rural-Urban migration. Red rectangle represents those drivers that are not easily researchable because of lack of data (Developed by the researcher)

As in Geist and Lambin (2002) and Lambin *et al* (2003), the proximate drivers of deforestation in the Niger Delta can be interpreted as the direct factors which originated from change in landuse, thus directly impact the forest cover in the region (Table 6.2 and Figure 6.4). These factors include: Development of transport networks, traditional shifting cultivation, subsistence cultivation, plantation farming, firewood extraction and logging as in the case of Okomu Forest Reserve (Section 5.6.1). In this category is the extension of roads and canal contraction that appears to be contributing to rapid deforestation in the Delta. The construction of road networks in the Delta provides local people with accessibility to log the forest. On the other hand, underlying factors affecting deforestation in the Niger Delta include lack of political will and unenforced forest protection laws, corruption at all levels, pressure of immigration and the high population, and the unconcerned attitude of local people about the situation of the forest around them (Table 6.2). Since independence, Nigeria has been governed by political leaders who do not care about the environmental impacts of human activities, especially in the Niger Delta region. The situation has been made worst in the past two decades by corrupt governments, who led the country for no other reason than to enrich themselves and their family members.

The biophysical nature of some regions in the Delta encourages deforestation, but not in others. High deforestation is evident in lowland rainforest due to the fact that it contains dry and fertile soil and no periodic flooding. These characteristics encourage expansion of both farmland and urban area. A low rate of deforestation is observable in freshwater swamp and mangrove regions due to the waterlogged nature of the terrain, which does not support extensive farming.

Finally, the present study has revealed that these drivers do not act in isolation. Earlier studies in other parts of the tropics by Geist and Lambin (2002); Lambin *et al*. (2003); and Estes *et al.* (2012) have also shown this. What is evident in the present study is that both social and economic activities are the drivers of rapid construction of road, which encourages accessibility to the forested areas. Furthermore, both the social survey conducted here and the work of Ibaba (2010), it isnoted that corruption and lack of political will are the instigators of weak enforcement of environmental and forest laws in the Niger Delta, thus also contributing to deforestation. Proper implementation of forest policies and enforcement of the exiting environmental laws are the best options to eradicate deforestation in the Niger Delta (Kalu and Izekor 2006; Ehwarieme and Cocodia 2011). This point was one of the findings of the social survey; however, it is not at all clear how this can be achieved.

CHAPTER SEVEN
SUMMARY OF FINDINGS AND CONCLUSION

7.1. Summary of findings

This chapter provides a synopsis of what has been learnt from this study and relates these findings to broader environmental challenges in Nigeria and the entire Africa continent. Though, several remote sensing classification methods were used and their accuracies tested, the study found out that conventional classification methods are not accurate enough to show environmental changes in the Delta. It was apparent that there was switching within some classes in consecutive years during classification analysis. It was also clear that the effects of climate seasonality on Landsat data make monitoring and assessing changes in landuse cumbersome. Therefore, there is a need for further analysis to reduce classification errors. To improve classification accuracy therefore, a Decision Tree Reclassification (DTR) method was developed, that uses prior classifications and simple rules of those changes of landuse classes which can occur over time and those that do not. This method led to a considerable improvement in classification accuracy and was thus applied throughout the study.

Landuse change results revealed expansion of urban and farmland classes and significant reduction in forest. Urban areas expanded by nearly 85% between 1984 and 2011, while the area covered by farmland has increased approximately by roughly 17%. Though, farmland expands throughout the three decades of the study, the annual rate of change declined from 3.2% during 1980s, to 2.6% during the 1990s, and 2.4% during 2000s. This decline might be because in many areas, there is little land remaining that can be converted to agriculture.

The results revealed that 9000 km^2 forest cover was lost in the Delta region between 1984 and 2011, and that the rate of deforestation varies within different forest types. Lowland rainforest appears to have suffered most, compared to freshwater swamp and mangrove forests. Nearly 40% of the lowland rainforest has been lost over the past three decades. However, deforestation in freshwater swamp was only about 13% and mangrove 10%. The inter-annual rate of deforestation varies according to forest types. Lowland rainforest appears to have the highest rate of 0.7% per year, while freshwater swamp forest and mangrove are 0.2% and 0.1% respectively. NDVI was used to look at forest degradation. The results showed that the degradation is higher in lowland rainforest, followed closely by freshwater swamp forest, while mangrove had a much lower degradation rate. The average reductions in NDVI were 0.27, 0.26 and 0.11 for lowland rainforest, freshwater and mangrove respectively. There are spatial and temporal variations, not only in the rate of degradation, but also in the regional intensity of the deforestation in the different forest types in the Delta.

The results from social research showed that the drivers of these changes in the Delta, as revealed from remote sensing results, are multifaceted. Such drivers include the influence of human activities such as urbanisation, industrialisation, communal and commercial logging, which are enhanced by high and rapidly increasing population, accessibility to forest reserves through transportation network, and other infrastructure developed by the government as a result of oil production in the Delta. Corruption, lack of political will and unenforced environmental laws are other major drivers, though these are not easily understood in the Niger Delta because of lack of accurate data about them.

7.2.Dynamics of landuse in the Niger Delta

Landuse change and forest degradation analysis showed that the rate of deforestation varies within different ecological zones in the Delta. It appears that nearly all the primary forests in the lowland rainforest have been affected by human activities, and the near-primary forest occurs only in patches along creeks and rivers. Forest reserves in freshwater swamp and mangrove forests have lost less forests, because they are less useful for agriculture, due to seasonal flooding and the fact that they are waterlogged for most of the years. On the other hand, the forest reserves in lowland rainforest are being degraded and deforested at an alarming rate due to a combination of factors such as their utility for agriculture; the introduction of the Taungya system; accessibility created by road network; expansion of farmland; and illegal logging of trees.

The results from statistical analysis support many of the findings of remote sensing, that show the need to manage deforestation in the region, and understand the fundamental drivers. The majority of previous studies have claimed that deforestation in the Niger Delta results from population increase, oil exploration activities and farmland expansion. This study found out that at the scale of the entire Delta, urban expansion and population growth are not very strong drivers (though, they may well be drivers locally), but there appears to be a significant correlation between deforestation and distance to roads, thus accessibility to forest appears to be the key. Notwithstanding, the correlation between population growth and farmland expansion is also quite strong. On the other hand in reality, there are probably no sole driver of deforestation in the Delta, as illustrated in the conceptual model developed for this study, rather, there are multiple drivers. Studies elsewhere in other tropical regions have shown that there are multiple causes of deforestation (Geist and Lambin 2002; Lambin *et al*. 2003, Estes *et al.* 2012). Also, the results from social survey revealed that drivers of deforestation in the Delta are probably multiphase, including unenforced forest protection laws, corruption at all levels, pressure of increasing population and indifferent attitude of local people about the situation of the forest around them.

Oil pollution has long been recognised as a big problem in the Delta. Remote sensing was shown to be ineffective at monitoring the main problems such as oil spills and pollution from gas flaring, though it was useful at monitoring some of the environmental problems the industry has created, such as the destruction of mangroves by intrusion of seawater along canals. The case of Tsekelewu shows that the major factor responsible for destruction of this mangrove vegetation in the North-west of the Delta is the construction of artificial canals by Chevron Oil, between late 1970s and early 1980s in an area that is below sea level, thus allowing incursion of saline waters and the demise of freshwater mangroves. The results from the social survey broaden our understanding that the majority of people in this region depend on rivers for drinking and domestic uses, yet, many sources of water have been contaminated by salty water, which is neither good for drinking nor for domestic purposes.

The results obtained in this study are useful, not only to explain environmental problems in the Niger Delta region, but also is valuable to determine the relationship between landuse change, the drivers of change and biodiversity loss in the entire country, Nigeria. There appeared to be a relationship between landuse change and location of threatened and endangered endemic mammals in the Delta. The majority of endemic species are located in the freshwater swamp forests, according to Blench (2007). All these forest reserves experience a low deforestation rate, though there is an indication of a high rate of degradation resulting from selective logging and fuel wood collection. Based on the location of the biodiversity and increasing rate of logging in the freshwater swamp forest, it is obvious that this forest type requires urgent conservation priority. Hunting for wildlife is another major problem threatening the wildlife in the region. Amusa (2003) has also reported that communities living near a forest in Nigeria depend mainly on animal protein from bush meat; and provision of food and herbs for traditional medicine. The results from social survey have also shown that uncontrolled hunting of wildlife has led to biodiversity loss in the Delta. Effective enforcement of environmental and conservation law to reduce the rate of degradation and deforestation in the reserves should be a priority. It is apparent from the present study that Okomu, Taylor creek forest and other forest reserves in the mangrove zone should be seen as forest reserves for urgent conservation efforts.

In general, the results from this study demonstrated that Niger Delta environmental resources are undergoing severe degradation through unsustainable farming practices, rapid urban expansion, unregulated national parks and logging; and impacts of oil production that are contrary to sustainable environmental management. Based on the findings above, and the practicable conclusion of this study, it is apparent that much has to be done to save forest not only in the Niger Delta, but in the whole country, Nigeria.

7.2.1. Forest Conservation

Conservation policies in Nigeria need to be improved to eradicate further deforestation and loss of biodiversity in the region. Illegal logging, clearing of forest for plantation agriculture and uncontrolled hunting of wildlife has led to depletion of natural vegetation and biodiversity loss. Forest in the Niger Delta has been degraded for too long without any visible signs of conservation (Ite 2005).

It is obvious that Nigeria has a very poor record in terms of conservation, as a result of poor funding, unenforced legislation and poor administration of forest (Amusa 2003; Ite 2005; Ezebilo and Mattsson 2010a). Consequently, few forests in the Niger Delta are left with little or no pressures of degradation. The few forest reserves remaining in the region face threats from illegal logging, expansion of road networks with enhanced accessibility and impacts from oil production in the region (Morakinyo and Tooze 2007; Bown et.al. 2011). Therefore, effective enforcement of environmental law and conservation to reduce the rate of deforestation in the region should be a priority. It is apparent from the present study that Okomu, Taylor creek forest and the other forest reserves mentioned in this research are in most in need of urgent conservation efforts.

7.2.2. Environmental Legislations in Nigeria Need Reformation

Environmental degradation in Nigeria is not as a result of lack of environmental legislation; rather it is due to ineffective enforcement of law. There is a need to reform the existing environmental protection laws to enable proper enforcement. It is of no use if new laws were added to the existing ones, without providing an adequate mechanism for enforcement. However, studies have shown that development of effective strategies to achieve adequate reform and enforcement of forest conservation in the Nigeria is problematic (Ite 2001; Ezebilo 2010). Despite the fact that environmental degradation is now increasingly seen as economic loss in other parts of the world (Bown et.al. 2011), it is not seen like that in Nigeria. It is therefore essential that all stakeholders; both Federal and State Governments, NGOs, Nigerian Conversation Foundation (NCF), Niger Delta commissions such as NDCC and indigenous people work together for adequate conservation of forest resources in the region.

In addition, there should be a political will to encourage oil companies operating in the Niger Delta to be accountable. Studies have shown that oil spills are major environmental problems in the region (Ndubusi and Asia 2007; Ebeku 2006; Eregha and Irughe 2009; Enemugwem 2009; Babatunde 2010). Although, the present study could not validate the wider impacts of oil spill on the Delta environment, the study was able to establish that oil production activities have been the major causes of mangrove deforestation in the Delta, by presenting the case of Tsekelewu. This case study shows that improvement of environmental legislation and enforcement of current legislation in the Niger Delta is essential.

A further point that would help improve the situation is that the views of local people of the Niger Delta should be incorporated into the conservation and environmental legislation system. This though will be a big challenge, as it has been shown from the social survey that many people depend on forest as sources of fuel for cooking; they have to be educated to see the reasons to embrace protection of forest reserves around them. Provision of alternative energy for indigenous people of the Delta, who depend mainly on forest for fuel, might reduce the rate of forest degradation in the region. Earlier study by Ajake and Anyandike (2012) has noted that effective conservation is possible in Niger Delta, if only the indigenous people were incorporated in the conservation scheme. The study concluded that governments and forest management institutions should encourage Delta community, and work together as one team for effective conservation of the Delta.

7.3. Further Work

Continuation of this monitoring into the future is one research aspiration in order to contribute towards systematic monitoring and management of the environmental resources and aid better environmental planning.

Evaluating the utility of NigeriaSat is another future research priority. Landsat and Nigeriasat-1 sensors have comparatively similar spatial resolution: 32m pixel for Nigeriasat-1 and 30m pixel for Landsat ETM. Also, the spectral range of Nigeriasat-1 bands 1, 2 and 3 are equivalent to that of Landsat ETM+ bands 4, 3 and 2. On the other hand, Nigeriasat-1 has a swath width of 640km, compared to 183km of Landsat and this can cover the majority of the

Delta in one image. It would be interesting to evaluate and compare the performance of both sensors for this type of research.

The findings of this study are useful to determine the relationship between biodiversity loss and landuse change in the Delta. Further work should carry this study forward to perform a detailed assessment of the significant impacts of landuse change on biodiversity. It would be interesting to know both plant and animal species affected by the environmental change looking at each of the forest reserves in details. Once this data has been put together, it can be combined with the information on deforestation and forest degradation developed in this study, in order to determine where the most threatened biodiversity lies and where the priority areas for protection might be. This information could then be presented to the Nigerian Conservation Society in order to develop a plan to conserve the most threatened protected areas/animals.

Given the role that roads play in promoting deforestation, there is a need to carry out the Environmental Impacts Assessment (EIS) of the proposed construction of trunk road between Oron and Warri (Figure 7.1). The road will cut across freshwater swamp and mangrove forests. It has been reported from our results that these two forest types have been spared from major disturbance so far, but construction of major road across these forest regions will no doubt promote deforestation and affect both plant and animal lives. Though construction of major roads like this, has both social and economic benefits to the government, local people and industrial sector, the environmental impact is likely to be enormous.

Assessing oil pollution using Landsat data is not possible due to low spatial and temporal resolution and the problems of cloud cover. Developing a remote sensing methodology to monitor oil pollution in the Delta region using RADAR or high resolution remotely sensed data such as Quick Bird is of a future research priority.

Finally, an important future development would be to expand the monitoring system developed here across wider areas of Nigeria, in order to provide a more comprehensive assessment of deforestation in the country.

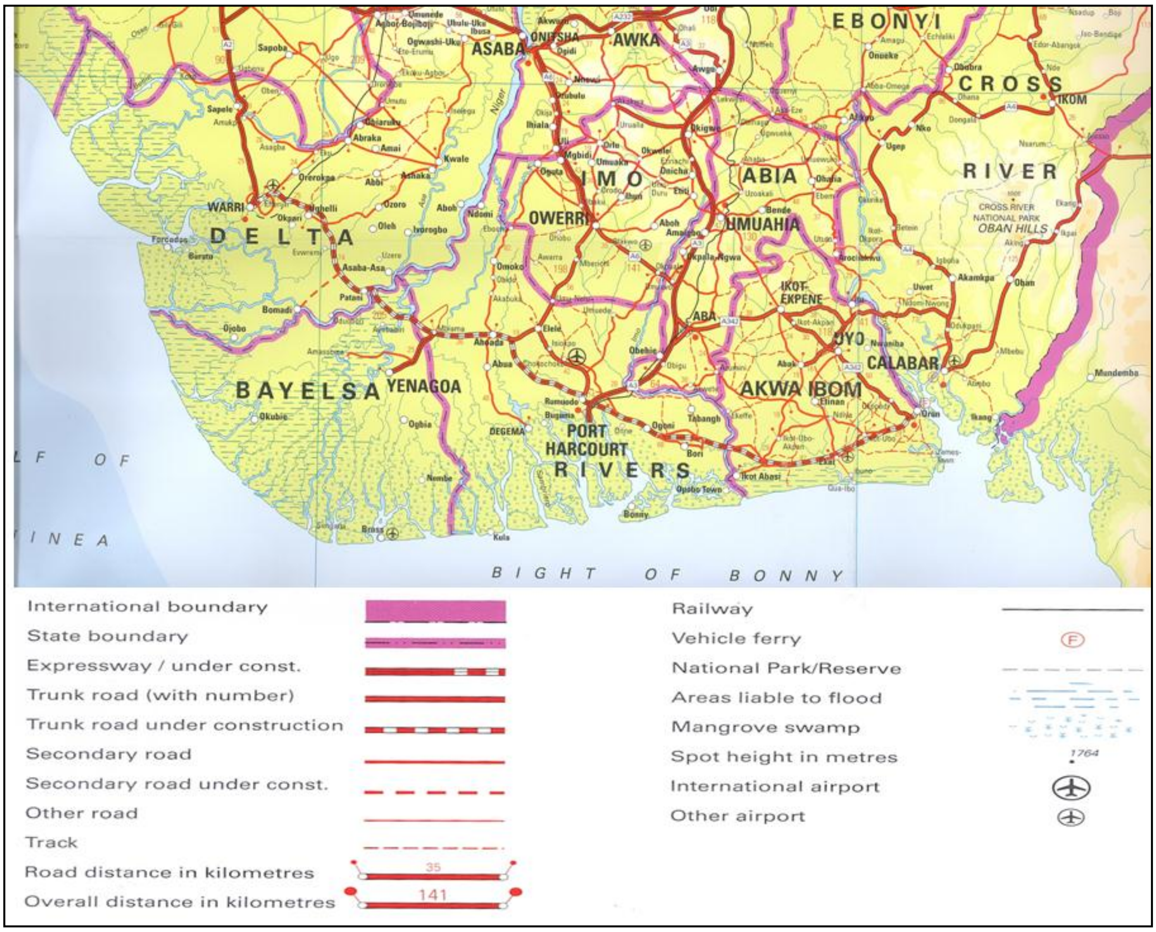


Figure 7.1. Map of the Niger Delta showing the location of trunk road under construction (after Safari map 2011)

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8.2. Appendices

8.2.1 Appendix A: Research Ethics Approval

Ayansina Ayanlade
Department of Geography
17th November, 2011

KING'S College LONDON
University of London

Dear Ayansina,

REP(GGS)/11/12-5 'Remote sensing of environmental change in Niger Delta'.

I am pleased to inform you that the above application has been reviewed by the GGS Research Ethics Panel and that FULL APPROVAL is now granted.

Please ensure that you follow all relevant guidance as laid out in the King's College London *Guidelines on Good Practice in Academic Research* (http://www.kcl.ac.uk/college/policyzone/assets/files/research/good%20practice%20Sept%2009%20FINAL.pdf).

For your information ethical approval is granted until 16th November 2012. If you need approval beyond this point you will need to apply for an extension to approval at least two weeks prior to this explaining why the extension is needed, (please note however that a full re-application will not be necessary unless the protocol has changed). You should also note that if your approval is for one year, you will not be sent a reminder when it is due to lapse.

If you do not start the project within three months of this letter please contact the Research Ethics Office. Should you need to modify the project or request an extension to approval you will need approval for this and should follow the guidance relating to modifying approved applications: http://www.kcl.ac.uk/research/ethics/applicants/modifications.html

Any unforeseen ethical problems arising during the course of the project should be reported to the approving committee/panel. In the event of an untoward event or an adverse reaction a full report must be made to the Chairman of the approving committee/review panel within one week of the incident.

Please would you also note that we may, for the purposes of audit, contact you from time to time to ascertain the status of your research.

If you have any query about any aspect of this ethical approval, please contact your panel/committee administrator in the first instance (http://www.kcl.ac.uk/research/ethics/contacts.html). We wish you every success with this work.

Yours sincerely

Daniel Butcher
Research Ethics Officer

8.2.2 Appendix B: Research Information Sheet for Participants

INFORMATION SHEET FOR PARTICIPANTS

KING'S College LONDON

University of London

REC Protocol Number:[INSERT ONCE PROVIDED BY REVIEW BODY]

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Remote sensing of environmental change in the Niger Delta

We would like to invite you to participate in this postgraduate research project. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

- The main aim of this part of the study is to investigate the view of local people and local health practitioners on the possible health effects of oil spills from oil exploration and drilling activities in the Niger Delta. The benefits of the study will be that efforts to control oil spill will be better targeted at primary advance effects on people health.
- Local persons living in the sample areas will be recruited through village leaders. Participant will all be over 18 years of age.
- If you agree to participate you will be asked to take part in an interview or from group in your own village or working place at a prearranged time to be suit you. Interview will take less than 20 minutes and group session will be less than 30 minutes.
- There are no foreseeable risks to you, all names will be kept security and spate from the data and will not be included in the final report. We will not be asking disturbing questions.
- Only the researcher who interviews you will have access to your name.
- The questions asked in the interviews and discussed in the focus groups will relate to your experience of oil spill and whether you believe they have resulted in adverse effects on people's health.
- If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form.
- In addition to withdrawing yourself from the study, you may also withdraw any data/information you have already provided us until it is transcribed for use in the final report by June, 2012.

It is up to you to decide whether to take part or not. If you decide to take part you are still free to withdraw at any time and without giving a reason.

If this study has harmed you in any way you can contact King's College London using the details below for further advice and information: Ayansina Ayanlade or Michael Howard email Michael.howard@kcl.ac.uk, Dept. Of Geography, King's College, London, UK. WC2R 2LS

8.2.3 Appendix C: Consent Form for Participants of the focus Group Discussions, Interviews and Questionnaires

CONSENT FORM FOR PARTICIPANTS IN RESEARCH STUDIES

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: ___ Remote sensing of environmental change in the Niger Delta

King's College Research Ethics Committee Ref: ________________

- **Thank you for considering taking part in this research. The person organizing the research must explain the project to you before you agree to take part.**

- **If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.**

...

- ***I understand that if I decide at any time during the research that I no longer wish to participate in this project, I can notify the researchers involved and withdraw from it immediately without giving any reason. Furthermore, I understand that I will be able to withdraw my data up to the point of publication.***
- ***I consent to the processing of my personal information for the purposes explained to me. I understand that such information will be treated in accordance with the terms of the Data Protection Act 1998.***

Participant's Statement:

I ____agree that the research project named above has been explained to me to my satisfaction and I agree to take part in the study. I have read both the notes written above and the Information Sheet about the project, and understand what the research study involves.

8.2.4 Appendix D: Questionnaire

Department of Geography

Obafemi Awolowo University, Ile-Ife, Nigeria

Health Effect Questionnaire for Residents

This questionnaire is intended to collect information *that would be used to study local awareness on impact of oil exploration in this community. The answer provided will be treated with all confidential*

1. IDENTIFICATION

1.1 Name of community________________________ **1.2 Date _____/________/_______**

1.3 Name of Street ___________________

2. DEMOGRAPHIC CHARACTERISTICS

2.0 **Age** 2.1 **Sex** A. M B. F 2.2**. Occupation__________________**

3.	**Health perception after oil spill and other environmental change**	Code	Answer
3.1a 3.1b	Do you have experience oil spill in your area? Do you think there have been any advance effects on people's health due to oil spills in your village/town?	1. Yes 2. No 1. Yes 2. No	
3.2	Are you anxious/worried about the ill health effect of the oil spill?	1. Yes 2. No	
3.3	Do you think oil spill has caused you ill?	1. Yes 2. No	
3.4	How many people fell ill in your home?		
3.5	How you can best explain the course of the illness after oil spill *(For only those who reported any symptom after spill)*	1. Same as before 2. Illness replaced after getting better 3. Getting better with time 4. Getting worse with time	

4. Did you have any of the following symptoms after oil spill in your area?

(Multiple symptoms can occur mark all that happened)

4.1. Dry throat	1.Yes 2. No		4.7. Skin swelling	1.Yes 2. No	
4.2. Scratchy throat	1.Yes 2. No		4.8. Itchy skin	1.Yes 2. No	
4.3. Sore throat	1.Yes 2. No		4.9. Skin irritation	1.Yes 2. No	
4.4. Stomachache	1.Yes 2. No		4.10. respiration problem	1.Yes 2. No	
4.5. Abdominal pain	1.Yes 2. No		4.11. Another symptoms		
4.6. Diarrhea	1.Yes 2. No		4.12. Does any of this affected your child(ren)?	1.Yes 2. No	

Public perceptions of official response: For each of the following, would you *rate their response* to the oil spill as…	**Excellent**	**Good**	**Fair**	**Poor**
Federal Government				
State Government				
Local Government				
Environmental Agencies				
Oil companies				
NGOs				
Village leaders				

Public trust: How much do you trust each of the following to *give accurate and Reliable information* about the oil spill…	**A great deal**	**A good amount**	**Not very Much**	**Not at all**
Federal Government				
State Government				
Local Government				
Environmental Agencies				
Oil companies				
NGOs				
Village leaders				

Thank you.

8.2.5 Appendix E: Focus Group Discussion on Landuse Change

FOCUS GROUP DISCUSSION

Theme of discussion: *Landuse change as perceived by people in the study area.*

The main objective *of this discussion is to determine how people in this settlement felt about the environmental changes going on around them. The discussion will take around 30 minutes. There are no foreseeable risks to you, all names will be kept security and spate from the data and will not be included in the final report. We will not be asking disturbing questions. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form* **(This objective will be read out to the people before stating the question**)

Questions:

1. What do you think has been the significant landuse changes (e.g. Urban expansion; deforestation; expansion in farmland; others) in your area over the last 30 years?
2. Were there any other changes in your environment over this time?
3. What do you think caused these changes?
4. What are possible wildlife in this reserve?
5. What do you think are the consequences (Positive and negative) of these changes? *Further questions on the consequences included the migration and immigration of people, conflict over land among local people, Conflict over land between local people and other land user (e.g oil and gas companies) and any other related issues they felt were important*.
6. What do you think are the consequences of deforestation and other landuse changes on the wildlife in this forest?
7. What can be done to eradicate or reduce the effects of these changes in this community?

8.2.6 Appendix F: Focus Group Discussion on Oil Impacts

FOCUS GROUP DISCUSSION

Theme of discussion: *Impacts of oil production infrastructures construction and Landuse change as perceived by people in the study area.*

The main objective *of this discussion is to determining how people in this settlement felt about the environmental changes (especially, contraction of artificial canal) going on around them. The discussion will take around 30 minutes. There are no foreseeable risks to you, all names will be kept security and spate from the data and will not be included in the final report. We will not be asking disturbing questions. If you do decide to take part you will be given t information sheet to keep and asked to sign a consent form* **(This objective will be read out to the people before stating the question**)

Questions:

1. Do you know when oil field/well, pipelines, artificial canals and other oil production infrastructures were constructed in this area?
2. What do you think has been the significant landuse changes (e.g. Urban expansion; deforestation; expansion in farmland; others) in your area over the last 30 years?
3. Were there any other changes in your environment over this time?
4. What do you think caused these changes?
5. What do you think are the consequences (Positive and negative) of these changes? *Further questions on the consequences included impacts on mangrove vegetation, farmland; migration and immigration of people, conflict over land among local people, Conflict over land between local people and other land user (e.g oil and gas companies) and any other related issues they felt were important*.
6. What can be done to eradicate or reduce the effects of these changes in this community?

8.2.7 Appendix G: Interview of Environmental Professionals

Statement of Agreement

This interview is designed to be used in a PhD research. The research aims at assessing environmental change and its impacts on social and health of people in the Niger Delta. Your experience and knowledge of environmental degradation is needed as part of qualitative information for this PhD research.

The interview will take around 30 minutes. There are no foreseeable risks for you, all names will be kept secured and spate from the data and will not be included in the final report. We will not be asking disturbing questions.

Moreover, you are free to withdraw from this interview as any point, if you are not comfortable. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. Thank you.

Questions:

1. What do you think has been the significant changes in the forest reserve in the Niger Delta over the last 30 years, in terms of deforestation, proportion of flora/fauna, and change in landcover/landuse?

Please, sir/ma, observe the maps below: they are from remote sensing analysis, showing spatial and temporal rate of deforestation in major forest reserves in the delta (***I will explain all the strange terms used and the maps further to the participants***).

2. Since you are familiar with forest reserves in the Niger Delta, do you think that these maps have accurately depicted changes in the forest reserves/national parks or do you think the map is in contrast with reality of the forest reserves? In what way?
3. Which of these do you think are the major causes of the forest changes in the delta: Increase in population or rural-urban migration; accessibility to forest through road network, urban expansion, farmland expansion such as increase in oil plantation in the delta or any other drivers you think?
4. Do you think that environmental changes in the Niger Delta are the results of oil productions in the region? Why do you think this, please, could you explain?
5. What do you think are the consequences of these changes on people living around the forest reserves? Please, Could you give some detail or examples?
6. What do you think are the consequences of deforestation and other landuse changes on the wildlife in these forests? Why do you say this, do you see the animals etc yourself, or hear from others?

7. Do you think landuse change or hunting is causing decline of animals in the various parks in the Delta? Why do you say this? *Further questions will be asked on the consequences on the wildlife including types of endemic and threatened wildlife in the delta possibly affected by these changes.*
8. What have been the efforts of Nigeria Conservation Foundation (NCF) and other environmental protection organisations in forest regeneration around the Niger Delta? Could you give me some examples? *Further questions on the strategies of NCF on conservation of forest in the delta and what have been their successes and limitations.*
9. Do you think that the increase in deforestation rate and other environmental change in the delta are results of lack of political will? Please, Could you give some detail or examples?
10. Some studies have reported that unenforced environmental protection law is one of catalyst of increasing deforestation in the delta, do you agree with this? Why do you say this?
11. What can be done to eradicate or reduce forest degradation and environmental degradation in the Niger Delta? *Further questions on this will include the assessment of conservation policy in Nigeria: success and limitations.*

8.2.8 Appendix H: Interview of Health Professionals

Statement of Agreement
This interview is designed to be used in a PhD research. The research aims at assessing environmental change and its impacts on social and health of people in the Niger Delta. Your experience and knowledge of health impacts of environmental degradation is needed as part of qualitative information for this PhD research.

The interview will take around 30 minutes. There are no foreseeable risks for you, all names will be kept secured and spate from the data and will not be included in the final report. We will not be asking disturbing questions.

Moreover, you are free to withdraw from this interview as any point, if you are not comfortable. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. Thank you.

Questions:

- Do you think there has been any advance effects of oil production on people's health your village/town?
- How you can best explain the course of the illness from oil production *(For only those who reported any symptom after spill)*
- Are there reported cases of health effects of oil exploration activities in this community?
- Do people reported to your clinic or find other medical means?

8.2.10 Appendix I: Sample points taken within homogeneous subsample locations in sampling areas for the entire Niger Delta

	Okitipupa/ Irele	Okomu forest reserves	Tsekelewu	Port Harcourt	Eket	Oboolo	Total
Sample areas (ROIs)	1	1	1	3 PH north, centre and south	3 PH north, centre and south	1	10
homogeneous subgroups – Polygons (called Pgs)	18	18	18	54	54	25	187
Simple points in each Pgs	10	10	10	10	10	10	10
Total sample points	180	180	180	540	540	250	1870

8.2.11 Appendix J: Worksheet plan used during fieldwork (three weeks at each location), showing the summary of field work activities.

Major Activities	**Week 1**							**Week 2**					
Planning	*	*											
Recognisant survey			*	*									
Data Collection					*	*		*	*	*	*	*	*
Reporting													

Location to visit	**Abuja**	**Okitipupa and Irele**	**Okomu and Gilli-Gilli forest reserve and national park**	**Tsekelewu**	**Eket**	**Port Harcourt and Oboolo**
Beginning Date of Fieldwork	***01/11/2011***	***08/11/2011***	***22/11/2011***	***6/12/2011***	***14/12/2011***	***22/12/2011***
Ending Date for Fieldwork	***0 7/11/2011***	***22/11/2011***	***6//12/2011***	***13/12/2011***	***21/12/2011***	***14/01/2012***
Field tasks on each location	1. NNPC office- To collect data on oil spill, location of oil and gas field, Maps........ 2. NPC office- To collect resent population data, Maps.... 3. NOSDRA Office- To collect oil spill data and location of major oil spill in Nigeria	1. Validating classification maps with sample location. 2. Taking GPS samples 3. Visiting location of forest reserves which is not in debase of WFO 4. Validating location of consistent bare ground 5. Interview and focus group about environmental change in the community 6. Taking digital photo and video records 7. Field note.	1. Visiting and interviewing the manager of Okomu and Gillli-Gilli forests. 2. Visiting and interviewing the manager of oil palm company Okomu 3. Visiting location of major forest degradation in Okomu and Gillli-Gilli 4. Validating the preliminary results 5. Taking GPS records 6. Interview and focus group discussion some villages around the forest reserve 7. Field note.	1. Visiting location of major canal contractions impacts 2. Questionnaire (among local people) on impacts of canal construction and inflow of salty water on people around the area. 3. Interviewing health practitioners about the impacts on health. 4. Taking GPS, digital photo and video records 5. Field note	1 Visiting location of major oil exploration impacts *2* Questionnaire (among local people) on impacts of oil exploration on people around the area. *About 150 questionnaires in at least three villages around oil exploration area.* 3 Interviewing health practitioners about the impacts on health. 4 Taking GPS, digital photo and video records 5 Field note	1. Validating classification maps with sample location 2. Visiting and interviewing the manager of Risonpalm and Abia oil palm plantation 3. Validating location of consistent bare ground and other landuse change 4. Taking GPS records 5. Interview and focus group discussion about environmental change in the community. 6. Taking digital photo and video records. 7. Field note

8.2.11 Appendix K Contd: Equipment and field assistants for the Fieldwork (Three weeks at each location).

Field personnel and equipment	**Detailed description**
Field assistants	16 field assistants were employed: 2 master students from OAU Nigeria: one of these students is originally from Okitipupa and Irele community. 2 undergraduate students from OAU Nigeria: The student is originally from Tsekelewu and Eket community. 12 local persons living in the village nearest to the field areas: 2 persons were hired in 6 field areas, to work with us for at least two weeks.
Images and Maps	1. A3 maps of change in Okitipupa 2. A3 maps of change in Okomu and Gillii-Gilli 3. A3 maps of change in Eket 4. A3 maps of Sample areas in Okitipupa 5. A3 maps of Sample areas in Okomu and Gillii-Gilli 6. A3 maps of Sample areas in Eket 7. A3 maps of Sample areas in Port Harcourt 8. A3 maps of Sample areas in Oboolo 9. A4 maps (18 copies) of Sample points in Okitipupa 10. A4 maps (18 copies) of Sample points in Okomu and Gillii-Gilli 11. A4 maps (18 copies) of Sample points in Port Harcourt 12. A4 maps (18 copies) of Sample points in Eket 13. A4 maps (18 copies) of Sample points in Oboolo
Equipment	4 GPS and camcorder: these were used for GPS coordinates of sampling stations and photo documentation of field sampling Map and Processed Image: for navigation around field sampling areas. VHF radio & Battery charger for VHF radio: to keep update on the news around Nigeria Field note: for documentation of field sampling and report writing, Questionnaires First aid kit: for immediate health issues